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Some Silurian Conodonts from the Southern Mackenzie Mountains, Northwest Territories

by

D. Jeffrey Over

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF Master of Science

Department of Geology

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Some Silurian Conodonts from the Southern Mackenzie Mountains, Northwest Territories submitted by D. Jeffrey Over in partial fulfilment of the requirements for the degree of Master of Science.

Abstract

Conodonts were collected from near Avalanche Lake, in the Glacier Lake map-area. The conodont fauna is diverse. The elements are black, 5 on the conodont Color Alteration Index.

The Silurian tectonic setting in the Avalanche Lake area was a continuation of the setting established by the Racklan Orogeny, the main elements being the Selwyn Basin and the Redstone Arch / Mackenzie Platform. Sediments assigned to the Road River Formation, consisting largely of fine clastics (shales), were deposited in the Selwyn Basin and along its margins. Carbonates and chert, assigned to the Whittaker Formation and the overlying Delorme Formation, are laterally equivalent platform deposits.

Avalanche Lake is in the area of the Early Silurian shelf / slope transition, characterized by interbedded units of argillaceous limestone, calcareous shale, chert, and dolostone. The shale intervals commonly contain a pelagic fauna of conodonts, conulariids, graptolites, and radiolarians, indicating deep, quiet water sedimentation. The limestone strata are dominated by a mixed pelagic and benthic fauna, characterized by brachiopods, conodonts, mollusks, ostracodes, sponges, and trilobites, indicative of deep shelf or slope sedimentation. Gravity flow deposits are common in some sections in the sequence.

Most of the conodonts in the sequence are cosmopolitan in nature. Fifty-seven species and subspecies of nineteen genera were identified, characteristic of the lower Llandovery to the upper Wenlock. The Ordovician-Silurian boundary is located within a 0.6 m section. In the study area the lowermost Llandovery is unzoned. The overlying deposits are divided, in ascending order, into the *discreta / kentuckyensis / nathani* Zone, the *celloni* Zone, the *amorphognathoides* Zone, the *patula / ranuliformis* Zone, and the *bohemica* Zone. Lineages of *Oulodus? fluegeli* (Walliser), *Oulodus? kentuckyensis* (Branson & Branson), *Aulacognathus bullatus bullatus* (Nicoll & Rexroad), *Ozarkodina gulletensis* (Aldridge), and a new genus of Pterospathodontidae can be used to further subdivide the established zones.

The Avalanche Lake conodont fauna is dominated by deep-water forms. Some intervals contain a mixed fauna, species indicative of intertidal and deep-water environments occurring in the same sample. Regional distribution of Avalanche Lake species indicates that the Selwyn Basin was not restricted in the early Silurian. Species migration and interchange occurred with the western United States, central United States, and Europe in the North American epeiric sea and in the deeper continental margin waters.

The form element *Johnognathus* Mashkova is placed in the apparatus of *Distomodus staurognathoides* (Walliser). New species and subspecies identified are *Apsidognathus* n. sp. A, *Aulacognathus bullatus* n. ssp. A, *Aulacognathus* n. sp. A, *Aulacognathus* n. sp. B, *Pterospathodus pennatus* n. ssp. A, *Oulodus?* n. sp. 1, *Oulodus?* n. sp. 2, *Oulodus?* n. sp. C, *Oulodus?* n. sp. D, *Oulodus?* n. sp. F, *Oulodus?* n. sp. I, *Ozarkodina* n. sp. A, *Ozarkodina* n. sp. B, *Ozarkodina* n. sp. D, *Ozarkodina* n. sp. I, and *Pseudooneotodus* n. sp. A. Two new genera are proposed. New Genus A was placed in the family Pterospathodontidae. New Genus B (composed of chirognathiform elements) was not assigned to a family. More complete multielement apparatuses were described for *Ozarkodina hadra* (Nicoll & Rexroad), *Apsidognathus tuberculatus* Walliser, and *Astropentagnathus irregularis* Mostler.

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1. INTRODUCTION

1.1 General Remarks

The first description of Silurian sedimentary rocks in the southern Mackenzie Mountains was by Keele (1910). He described dark grey limestones, argillites, some sandstones, and silicified beds along the Gravel (Keele) River. The age determination was made from corals and brachiopods. In-depth investigation of the geology of the western and southern Mackenzie Mountains started in 1942 with the Canol project. Though the main area of interest was in the vicinity of Norman Wells, Silurian sections were measured in the Keele, Redstone, and Nahanni River valleys. These beds are composed of grey limestone, which becomes cherty and dolomitized upward. These units, approximately 650 m thick, were assigned to the Franklin Mountain (Lower Silurian), Mount Kindle (Middle Silurian), and Lone Mountain Formations (Upper Silurian). Where distinctions were not evident, the term Ronning Group (obsolete) was used (Hume, 1954). The Franklin Mountain Formation is now considered to be Cambrian-Ordovician (Macqueen, 1970; Norford and Macqueen, 1975). The Mount Kindle Formation was redescribed as early Silurian by Norford and Macqueen (1975), and the Lone Mountain Formation was divided into two formations, the Arnica and Manetoe, both Devonian in age (Douglas and Norris, 1961). (See Figure 3, stratigraphic nomenclature, later in text.)

Geological Survey of Canada (GSC) mapping projects, Operation Mackenzie, Operation Nahanni, and related operations from 1957 to 1965, resulted in the mapping of most of the southern Mackenzie Mountains from the Mackenzie River to west of the Yukon/Northwest Territories boundary (Douglas and Norris, 1960, 1961, 1963; Green and Roddick, 1962; Gabrielse *et al.*, 1973). Silurian strata were included in the Road River Formation, Whittaker Formation, and Delorme Formation.

The GSC studies dealt largely with stratigraphy and structural relationships, using the abundant macrofossils for correlation and age determinations. Since the mapping projects, numerous systematic studies of various faunas have been published, though most have dealt with Ordovician and Devonian faunas and strata. Silurian studies began initially with graptolite research (Lenz and Jackson, 1964, 1971). Other works describe Silurian brachiopods (Lenz, 1977), ostracodes (Copeland, 1977, 1978a, 1978b; Jackson,

1978), rostroconchs (Johnston and Chatterton, 1983), trilobites (Perry and Chatterton, 1978; Chatterton and Perry, 1983, 1984), and graptolites, brachiopods and corals (Jackson *et al.*, 1978).

Conodont research in the southern Mackenzie Mountains has been minimal. Ordovician faunas were described by Tipnis *et al.* (1978), and McCracken and Nowlan (1984). Chatterton (1978) described Devonian conodonts from the same region. The Silurian conodont work is limited to brief mentions for age determinations and correlations (Hills, *et al.*, 1981; Cecile, 1982), and a graptolite-conodont correlation of the Ordovician-Silurian boundary (Lenz and McCracken, 1982).

The present status of the conodont animal is in the Phylum Conodonta (Eichenberg 1930, *sensu* Clark, 1981), confirmed by the finding of an *in situ* conodont apparatus and animal form of Mississippian age (Briggs *et al.*, 1983). Initial descriptions of conodont structures were of single elements, each assigned a species name. Natural assemblages of conodonts from shale bedding planes have been known since 1934 (Schmidt, 1934; Scott, 1934), but not until later did a nomenclature based on associations of elements come into use (see Bergström and Sweet, 1966; Klapper and Philip, 1971; Sweet and Schönlaub, 1975; Barnes *et al.*, 1978).

Silurian conodont faunas have been described from every continent. The world wide distribution of some species and provincialism of others in the Silurian and other periods has led to questions about the life modes and environmental preferences of the conodont animal. Of main conjecture is whether conodonts were planktonic, nektonic, or nektobenthic / benthic, and whether their habitats were controlled by depth, salinity, temperature, or other factors (Barnes and Fåhraeus, 1975; Klapper and Barrick, 1978). Different species probably had different life modes and filled various niches.

A number of schemes of conodont zonation have been erected for the Silurian. The zones are defined by appearance / extinction of certain species, and species associations (see Cooper, 1980). Zonations are somewhat restricted regionally, especially in the Llandovery, because of faunal differences (see Cooper, 1980). There are also local differences due to variation in species ranges.

1.2 Purpose

This study is designed to be of value in future correlation of Silurian strata in northwestern Canada. The purpose of this project is to erect a zonal scheme for Silurian conodonts in the southern Mackenzie Mountains, as well as to investigate multielement assemblages, evolutionary pathways, and paleoecology, and their relationship to stratigraphic units. The study was initiated by the finding of silicified trilobites in Silurian outcrop east of Avalanche Lake by A. Lenz in 1974. B. Chatterton and D. Perry collected and measured Silurian sections in 1978 and 1979 in the same area. Along with silicified trilobites, they found a diverse conodont fauna. This study includes their collections, as well as samples collected in 1983.

1.3 Study Area

The study area is in the southwestern Northwest Territories, Glacier Lake map-area, east of Avalanche Lake on the north limb of the Avalanche Syncline (Fig. 1). The measured sections are in the area of the Silurian basin-shelf break, in the transition between shelf carbonates and deep-water shales (Gabrielse *et al.*, 1973). The Paleozoic strata are in open folds, lapping onto horizontally lying Proterozoic sedimentary rocks to the north, and intruded by Cretaceous granites southwest of the study area. The conodont elements are black, 5 on the conodont color alteration index, indicating either burial below 8,000 m or shallow burial and local geothermal activity (Epstein *et al.*, 1977).

1.4 Method of Study

Samples from 1978 and 1979 are from horizons collected for apparent silicified trilobites from three sections. These sections were collected at 5 m vertical intervals in 1983, as well as three new sections to the east, presumably representing strata more distal from shore (Fig. 1). Samples averaged 4.8 kg. The samples collected in 1983 were dissolved in acetic acid, and the insoluble material was washed and sieved. The coarser than 120-mesh (0.125 mm) fraction was then separated using acetylene tetrabromide (s.g. 2.96) diluted with acetone to a density of 2.838. The heavy separate was then washed of heavy liquid and picked for conodonts. The 1978 and 1979 samples were largely processed and picked by B. Chatterton and D. Perry. Photographs were taken on an

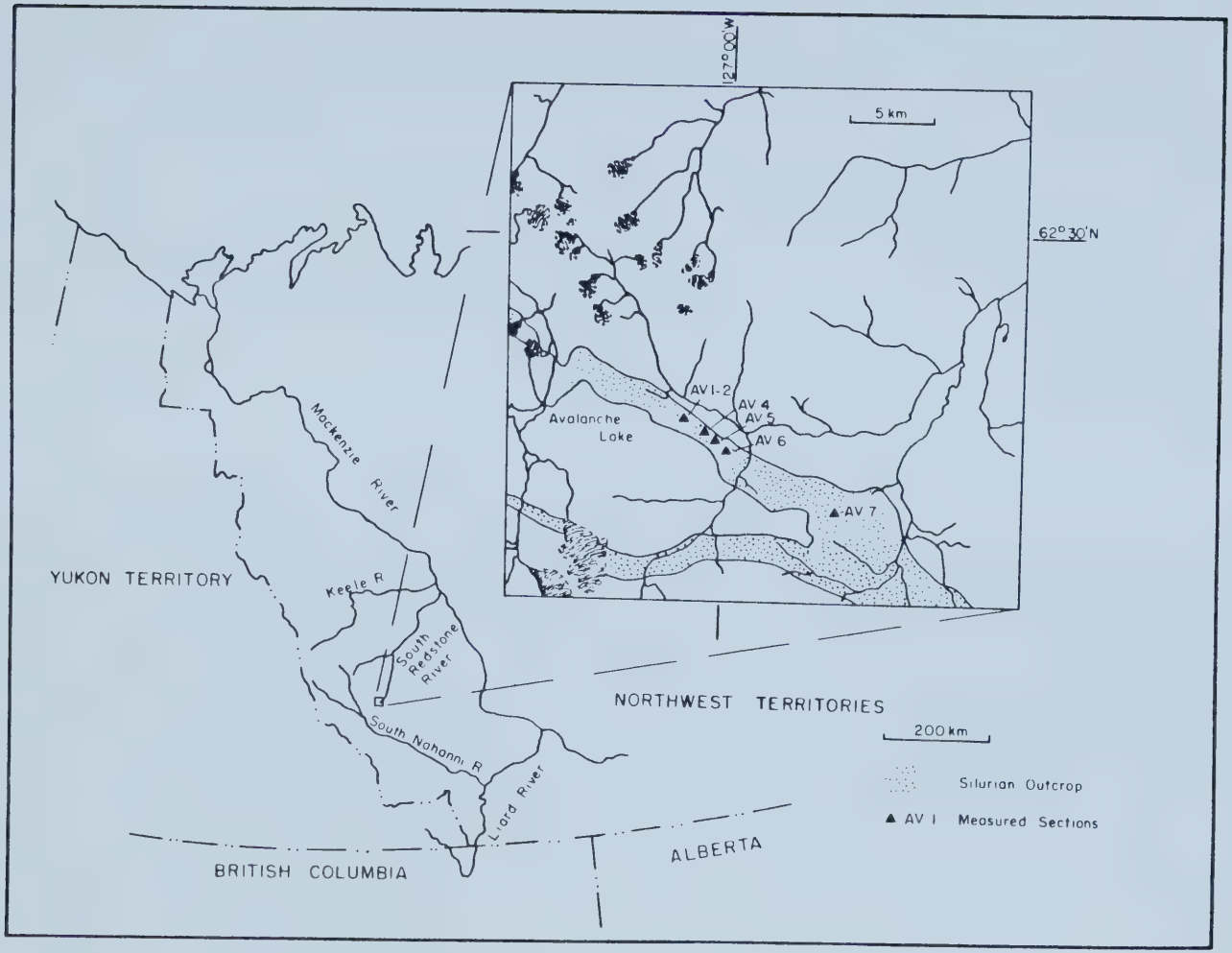

Figure 1 Study area and location of measured sections.

attachment to a Cambridge Stereoscan S 100 scanning electron microscope using Kodak 120 plus X film.

2. GEOLOGIC SETTING

2.1 Tectonic Setting

The structural setting of the Silurian depositional basins and arches was a continuation of the basin configuration of Neohelikian-Hadrynian time, formed by the Racklan (Grenville) Orogeny (Gabrielse, 1967). Racklan uplift, faulting, and minor volcanism occurred during deposition of the Rapitan Group, tilting lower lying Helikian deposits and Rapitan sediments. Uplift and tilting continued through the Late Proterozoic, forming depositional breaks at the base of the Lower Rapitan, the top of the same unit, and the top of the Middle Rapitan. The regional tectonic elements formed from Racklan activity in the southern Mackenzie Mountains were the Selwyn Basin, Root Basin, and the Redstone Arch/Mackenzie Platform (Fig. 2). These topographic highs and lows, positioned within 30° of the equator in Ordovician-Silurian time, persisted until the Devonian-Mississippian.

The Selwyn Basin extended parallel to the western edge of the craton, bounded on the north by the Ogilvie Arch and Redstone Arch/Mackenzie Platform. To the west and south the basin was bounded by the Yukon Plaform, Cassiar Platform, and MacDonald Platform. The area of the basin was on the order of 3500 km², extending approximately 700 km along the NW-SE axis. The basin was defined as a miogeosyncline by Kay (1951), indicating that it was downwarped continental crust. Blusson (1976) suggested that the Selwyn Basin should more properly be referred to as a trough, due to its shape and sediment fill.

Since the initial downwarp, the Selwyn Basin was the site of predominantly fine clastic deposition. The strata become coarser and more calcareous on the basin margins, grading into carbonates on the platforms. Some thin extrusives and local volcanic flows, Cambrian through Silurian, are present in the shale and carbonate sequences on the east and west edges of the basin (Gabrielse, 1967; Cecile, 1982).

The Redstone Arch was the site of thinning and erosion of late Precambrian and Paleozoic strata on the westward edge of Mackenzie Platform (Gordey, S., GSC, pers. comm., 1983). The arch trended NNW in a shallow arc, possibly linking with the Ogilvie Arch (Gabrielse, 1967). The Mackenzie Platform, of which the Redstone Arch is an

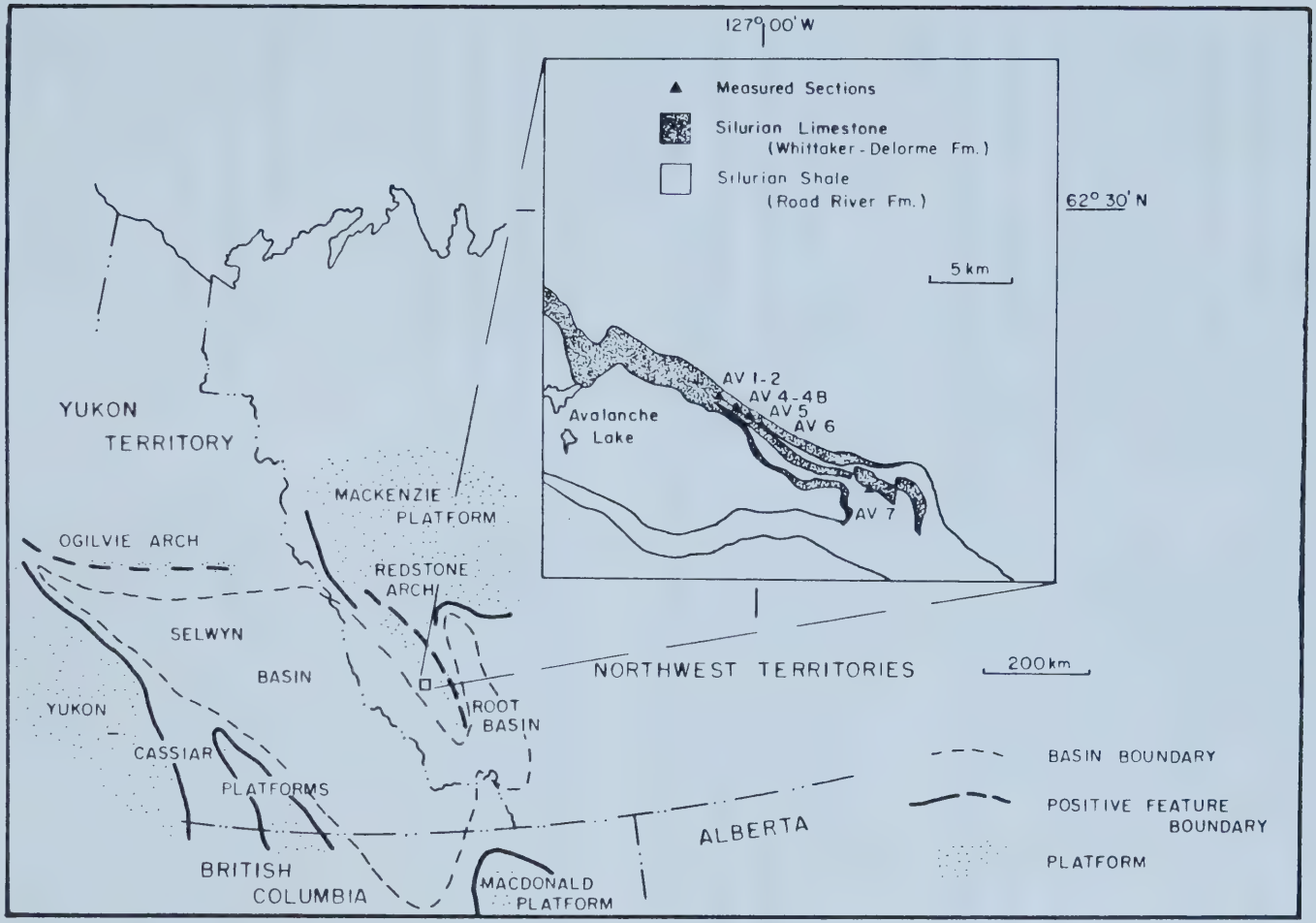

Figure 2 Tectonic setting of the southern Mackenzie Mountains region in the Silurian.

element, was the site of thick carbonate deposition for much of the Lower Paleozoic. Shales, continuous with deposits in the Selwyn Basin, were deposited on the platform during major rises in sea level. Periods of subaerial exposure or non-deposition occurred in the upper Lower Cambrian, at the top of the Middle Cambrian, at the top of the Middle Ordovician (base of the Whittaker Formation), along the Ordovician-Silurian boundary, and in the Middle Devonian (Gabrielse, 1967; Gabrielse *et al.*, 1973; Tipnis *et al.*, 1978; Lenz, 1982; Lenz and McCracken, 1982). Perry and Lenz (1978) stated that there is little evidence for subaerial exposure on the arch, due to the lack of significant amounts of coarse detritus, though some sandstone is found in Ordovician strata. Fluctuations in sea level are evident, possibly due to glacio-eustatic events (Berry and Boucot, 1973; Lenz, 1982).

The Redstone Arch/Mackenzie Platform was a barrier between the Selwyn Basin and the more restricted Root Basin to the southeast. The fauna differs somewhat between the two basins (Perry and Lenz, 1978; Chatterton and Perry, 1984), but the conodont faunas appear to be similar; concurrently, deep water faunas are replaced by progressively shallow water forms from the basins onto the platform (Ludvigsen, 1975; Copeland, 1977).

The Root Basin is along the southern margin of the Mackenzie Platform, forming what may have been a large restricted bay off the Selwyn Basin (Fig. 2). The Root Basin was the site of predominantly carbonate deposition, characteristically dolomitic, with some argillaceous material (Douglas and Norris, 1960, 1961).

2.2 Stratigraphy

The Road River Formation, Whittaker Formation, and Delorme Formation comprise the Silurian strata of the southen Mackenzie Mountains. These formations extend from the Cambrian-Ordovician to the Devonian. The Road River Formation is mainly shales, deposited in the Selwyn Basin and its margins. The Whittaker Formation and Delorme Formation are platform carbonates, though the thickest deposits are on the platform edge. The regional stratigraphic nomenclature is given in Figure 3.

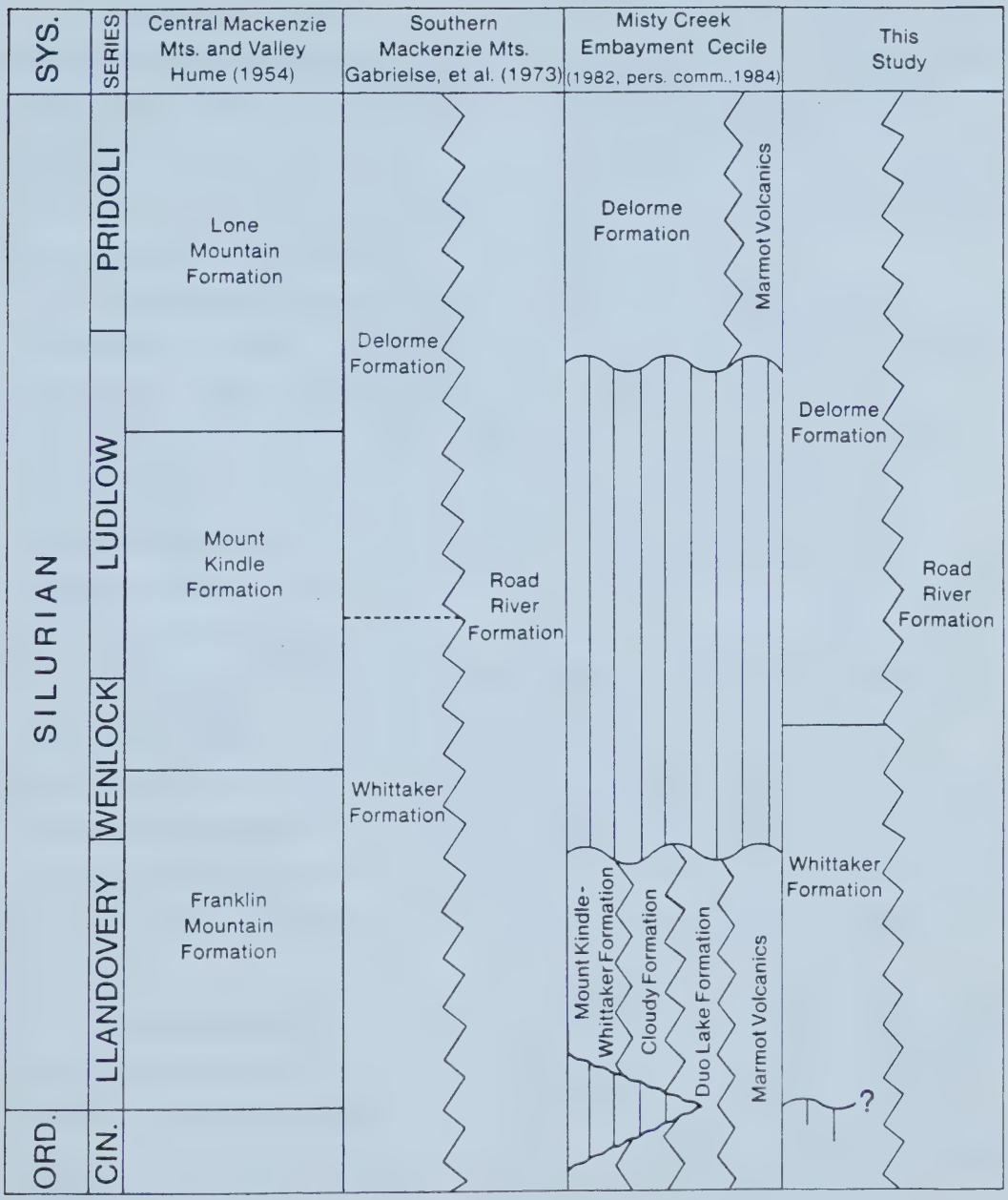

Figure 3 Stratigraphic nomenclature of Silurian strata in the southern Mackenzie Mountains. The formations established by Hume (1954) are obsolete. The Franklin Mountain Formation is considered to be Ordovician, the Mount Kindle Formation is Lower Silurian, the Lone Mountain Formation has been redefined into a number of Devonian formations.

2.2.1 Road River Formation

The Road River Formation is the name given to a wide range of lithologies, mainly dark colored shales, ranging in age from Early Cambrian to Devonian. The formation was named by Jackson and Lenz (1962) for 910+ m of alternating dark graptolitic shale, argillaceous limestone, and minor chert, dolostone, sandstone, and siltstone. The type section is along a tributary to the Road River, Yukon Territory. The Road River Formation has been described over the extent of the Selwyn Basin (see Fig. 2).

In the southern Mackenzie Mountains, the Road River Formation ranges from 1077 m to 3100+ m thick, the latter figure obtained from a central Selwyn Basin section (Cecile, 1978). The deposits in the southeast consist of black shale, argillaceous limestone, shaly chert and limestone (Cecile, 1978). To the southeast, the Road River Formation consists of pyritic calcareous black shale, chert, siltstone, dolomite, and thin-bedded black limestone (Gabrielse *et al*., 1973). The Road River Formation, in sections described by Gabrielse *et al*. (1973) from the Glacier Lake map-area, is absent to 671 m thick. These sections are close to the basin-platform margin, where the Road River grades laterally into the Sunblood Formation (Ordovician), Esbataottine Formation (Ordovician), Whittaker Formation (Ordovician-Silurian), Delorme Formation (Silurian-Devonian), and other Devonian carbonates. Strata equivalent to the Road River Formation to the northwest of the Avalanche Lake sections in the Misty Creek Embayment have been described and assigned to four formations (Cecile, 1982). Silurian strata are encompassed in the Duo Lake Formation, Cloudy Formation, and Marmot Formation (Fig. 3).

Measured sections AV 5 and AV 6 are located where the Road River Formation and Delorme Formation interfinger (Fig. 2). Member 2D at AV 4 is transitional between the Road River Formation and the Delorme Formation. The Road River Formation units are sparsely fossiliferous, dark grey calcareous shale and thin bedded argillaceous micrite and sparite, 120 m - 150 m thick. AV 7 is a 500 m thick section of strata assigned to the Road River Formation, composed of calcareous shale and thin bedded limestone.

2.2.2 Whittaker Formation

The Whittaker Formation was named by Douglas and Norris (1961) for a thick sequence of limestone, dolomite, and shale overlying the Sunblood Formation. The type section is located in the Whittaker Range, Northwest Territories, totalling 1252 m thick. This section was divided into three main units by Douglas and Norris (1961). These units are regionally continuous, appearing throughout the southern Mackenzie Mountains (O'Bertos and Jackson, 1965). In the type section, the lower unit consists of 406 m of limestone, dark grey to grey weathering grey, fine- to medium-grained and thickly-bedded. Brachiopods from this unit were identified by B.S. Norford (*in* Gabrielse *et al.*, 1973) as Ordovician. A basal portion of the lower unit was assigned to the Esbataottine Formation when the Whittaker Formation was redescribed by Ludvigsen (1975). The middle unit consists of 265 m of fossiliferous dolostone, which is dark grey weathering light to dark grey, fine-grained, sparsely cherty and medium to thick-bedded. Corals identified by Norford and Sinclair (*in* Gabrielse *et al.* 1973), were assigned a Late Ordovician age. The upper unit, 582 m thick, is argillaceous limestone and siltstone, dark grey to black, fine-grained, and platy to thinly-bedded. Graptolites from this unit were dated by Norford and Thorsteinsson (*in* Gabrielse *et al.* 1973) as Llandovery / Wenlock.

The Whittaker Formation conformably overlies the Sunblood Formation and Esbataottine Formation in the Selwyn Basin and Root Basin, and on the basin margins. On the Redstone Arch / Mackenzie Platform, an angular unconformity separates the Whittaker Formation from Cambrian and Proterozoic rocks, notably the Broken Skull Formation (Cambrian), and the Little Dal Formation (Helikian). Conformably overlying the Whittaker Formation is the Delorme Formation. The top of the Whittaker Formation is defined by the last occurrance of dark fine-grained limestone, overlain by orange-brown weathering dark grey shale and bedded dolomitic siltstone of the Delorme Formation. Silurian equivalents to the Whittaker Formation are the Mount Kindle Formation and the Road River Formation.

Sections of the Whittaker Formation in the Avalanche Lake area, measured by Gabrielse *et al.* (1973), were 198 m and 790 m thick (Section 42 and Section 44). Both sections are on the platform side of the basin-platform transition, though proximal to the facies boundary. To the southwest, on the opposite limb of the Avalanche Syncline and

basinward of the facies boundary, the Whittaker Formation is replaced by the stratigraphically equivalent Road River Formation. Sections AV 1 and AV 4B, both containing the Ordovician-Silurian boundary, contain upper Whittaker Formation (Silurian) sections approximately 375 m thick. The dominant lithologies are dark fine-grained limestone, commonly argillaceous and sparry, and dolomitic chert. These sections are lithologically similar to the type section, though possibly containing less clastic material.

2.2.3 Delorme Formation

The Delorme Formation was named by Douglas and Norris (1961) for "a sequence of buff and light brown weathering, thinly bedded limestones, dolomites and shales that overlie the Whittaker Formation..." The type section is 990 m thick, located in the headwaters of Pastel Creek, Delorme Range, Northwest Territories. Morrow and Hills (1981) stated that the type section is not typical of the Delorme Formation throughout its mapped extent. The Delorme Formation is better recognized as interbedded dark grey shale and thin-bedded dolomitic siltstone, weathering bright orange. Some massive light grey dolostone and limestone occurs in the lower units, and thin-bedded light grey limestones occur in the upper strata. A more typical Delorme Formation section is located on the east flank of the Whittaker Anticline (Morrow and Hills, 1981). The Delorme Formation ranges in age from Silurian to Early Devonian.

The Delorme Formation conformably overlies the Whittaker Formation, and is conformably overlain by the Camsell Formation (Devonian), or the Sombre or Arnica Formation (Devonian) where the Camsell Formation is absent. The Delorme Formation pinches out to the east, and grades into shales of the Road River Formation to the west.

Gabrielse *et al.* (1973) measured one section containing strata assigned to the Delorme Formation in the Avalanche Lake area (Section 44). The Delorme Formation unit was 643 m thick, consisting of orange and buff weathering dolostone. AV 1, AV 2, AV 4, AV 5, and AV 6 contain strata assigned to the Delorme Formation. The Whittaker-Delorme Formation contact is defined by the change from dark grey limestone to orange-brown shale. Above the shale unit, which is potentially assignable to the Road River Formation, the Delorme Formation is thin-bedded grey limestone before grading into

massive light grey dolostone typical of the description of Morrow and Hills (1981). Some calcareous and shaly beds occur in the dolostone sequence; one contained abundant inarticulate brachiopods and their burrows. The AV sections were not measured above the dolostone gradation due to the more shallow-water nature of the deposits and lack of recoverable conodonts (Chatterton, B., University of Alberta, pers. comm., 1982)

2.3 Depositional Environments

The seven Avalanche Lake (AV) sections measured and described are a sequence of argillaceous micrite, sparite, dolomitic chert, dolostone, and shale, all containing a minor amount of quartz sand and silt (Fig. 4). The lithology and incorporated fauna are diagnostic of deep-water deposits, the sediments supposedly deposited in a deep-shelf and/or slope setting. AV 1 and AV 2 are the most proximal to shore, AV 4, AV 4B, AV 5, AV 6 and AV 7 representing sections of progressively more distal and deeper water. There is no evidence of subaerial exposure during the time of deposition in the AV sections. A sea-level curve for the Avalanche Lake area in the lower-middle Silurian, as well as the composite curve constructed for the central Mackenzie Mountains by Lenz (1982), are given in Figure 5. The criteria used for determining the relative water depth are summarized by Lenz (1982). The local sea-level curve differs from the regional composite of Lenz (1982) in the scale of the major sea-level fluctuations, but for the Llandovery and Wenlock, the overall trends are similar.

2.3.1 Sedimentology

A number of thin sections and cut slabs were prepared from samples collected in 1983. These are believed to constitute a representative suite of the major lithologies. Other data were obtained from outcrop descriptions, sample descriptions, and acetic acid digestion residues.

The deposits have undergone soft sediment deformation and diagenetic alteration. Deformation was due to loading, compaction, and some slumping. Only minor folding is evident from later tectonism. Most of the micrite has been altered to microsparite with some dolomite replacement, or total replacement by sparite. Fossils that were originally

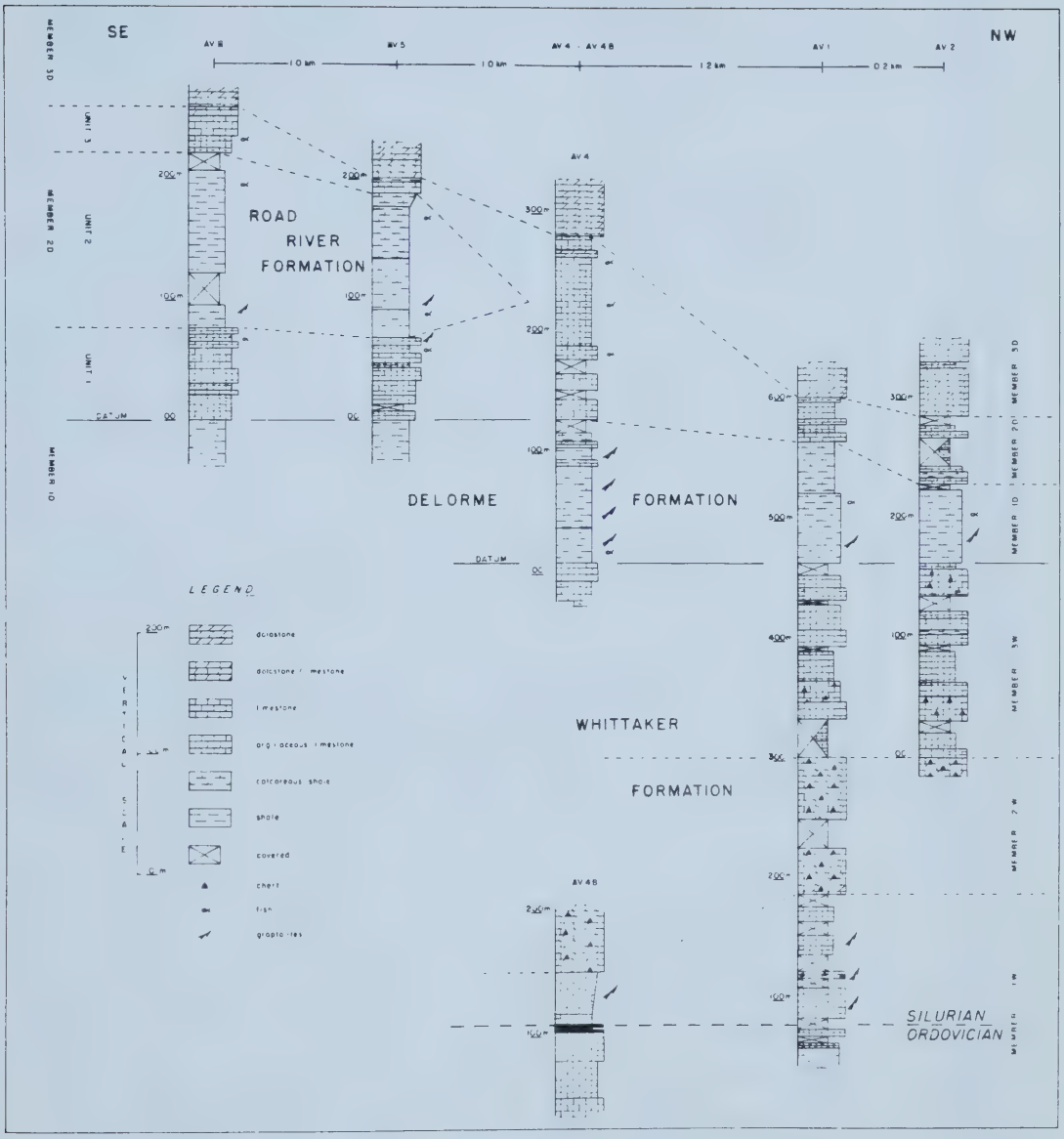

Figure 4 Lithologic correlation of AV sections. See Fig. 1 for location of sections. AV 7 is not illustrated.

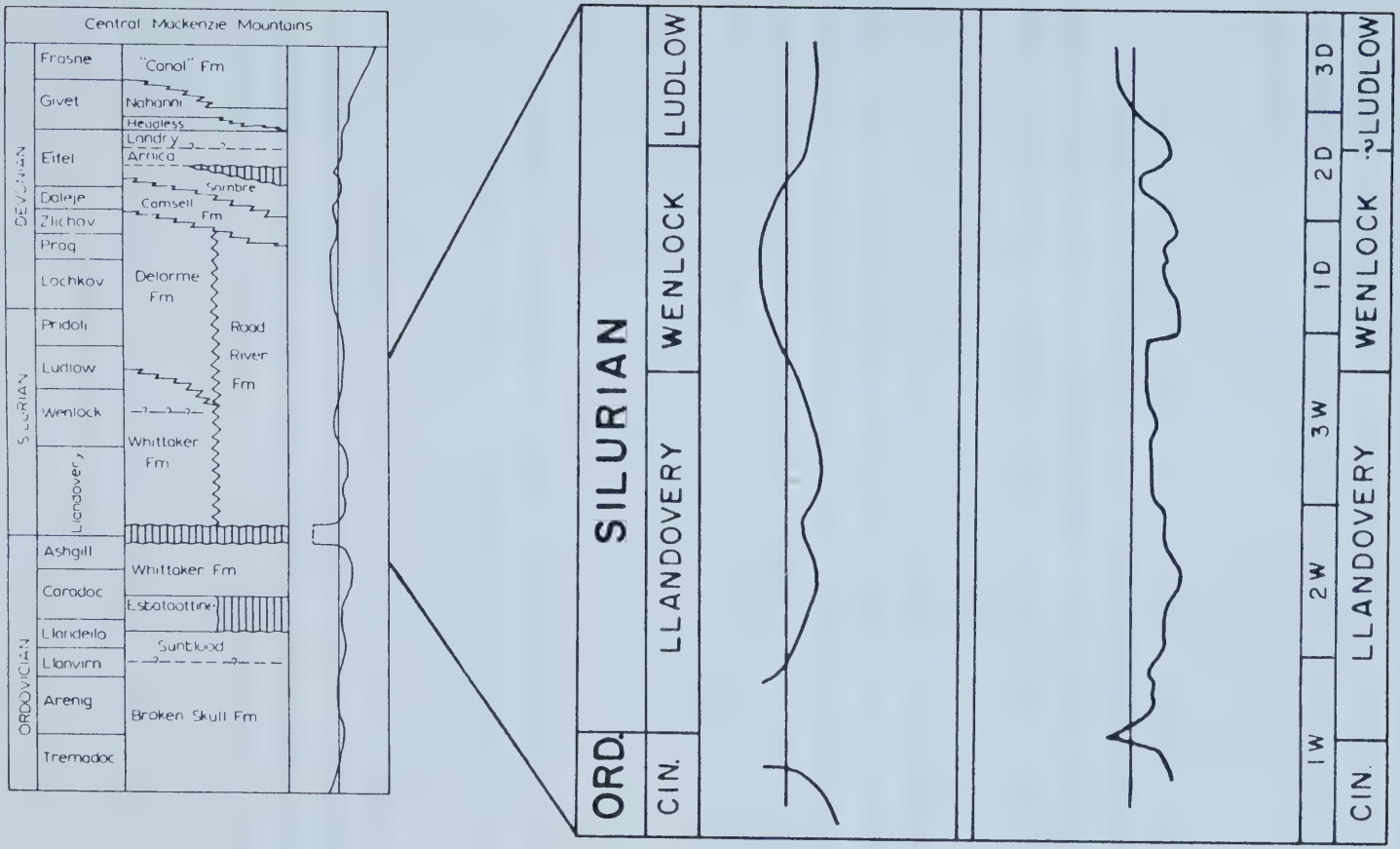

Figure 5 Sea-level curves for the central Mackenzie Mountains and the Avalanche Lake area. The diagram on the left is from Lenz (1982). The middle curve is an enlargement of the composite sea-level curve for the Llandovery and Wenlock. The curve on the right is for the Avalanche Lake area in the Lower Silurian; the right column corresponding to the lithologic members in Figure 4. The center line of the Avalanche Lake curve corresponds to a "middle shelf" water depth.

aragonite or calcite have been replaced by silica, coarse calcite, or pyrite. Original siliceous material has largely been dissolved and the mold destroyed or filled with pyrite. Phosphatic material (conodonts, conulariids, fish plates, and inarticulate brachiopods) has been relatively unaltered. Many of the beds contain pyrite, or exude hydrogen sulfide when broken. In the thin sections examined, pore space is either absent or filled with hydrocarbons.

The sections are divided into six informal members based on overall lithology. They are, in ascending order beginning at the Ordovician-Silurian boundary (AV 1 approximately 80.5 m, AV 4B 111.6 m): Member 1W) a lower argillaceous micrite member, Member 2W) a calcareous dolostone and chert member, Member 3W) a middle argillaceous and bioclastic micrite / sparite member, Member 1D) a brown weathering shale member, Member 2D) an upper argillaceous and bioclastic micrite / sparite member, and Member 3D) a massive dolostone member (Fig. 4). The 'W' and 'D' in combination with the member number signifies informal members of the Whittaker Formation and Delorme Formation respectively. In the distal sections, AV 5 and AV 6, Member 2D is divided by a thick wedge of black shale, assigned to the Road River Formation. At these localities Member 2D is divided into three submembers.

Member 1W

Member 1W extends from AV 1 82 m - 185 m and AV 4B 111.5 m - 150 m. The rocks are generally dark grey to black, thin bedded, fine wavy-planar laminated argillaceous micrite, locally shaly and fossiliferous. Less argillaceous horizons, more common toward the base, are more resistant. Chert nodules are present at AV 1 102 m, 103.5 m, 120 m and AV 4B 142.5 m. The chert commonly forms in small spheres, connecting and forming nodules and beds. AV 1 95 m contains abundant euhedral gypsum crystals replaced by dolomite. AV 1 103.5 m has soft sediment boudin structures, formed by differential compaction. Beds at AV 1 140 m and 155 m have been replaced by dolomite. No bioturbation structures are evident. Fossils are either in place, as at AV 4B 111.5 m, or oriented parallel to bedding.

Member 2W

Member 2W extends from AV 1 185 m - 320 m, and the upper portion of AV 4B, above 154.5 m. The strata are generally calcareous dolostone, cherty dolostone, and dolomitic chert. The sediments are interbedded, medium grey to black, very thin to medium bedded, thinly laminated, recessive and weathering into irregular plates where shaly, or resistant and blocky. Where largely chert, the beds weather grey to orange, appearing as banded beds. The dolostones are fine to coarsely crystalline, with relict laminations.

Chert beds, mottled white-and-black to black, appear to be primary, or diagenetic, formed before major compaction. Laminations in underlying dolostone beds are deflected by chert beds. Some chert layers have erosional upper surfaces with truncated laminations. These surfaces are draped by laminations within the overlying dolostones. As a result of recrystalization, interpretation is difficult. The chert horizons are surrounded by coarse crystalline dolostone. This may represent chert formation in coarser sediment, or the coarse dolomite may be a secondary result of the chert deposits. Secondary euhedral dolomite rhombs occur within the chert beds.

The dolostones are finely laminated and calcareous, indicating that the dolomite replaced argillaceous micrites similar to the underlying deposits. The dolostones are medium grey, fine to coarsely crystalline. Poorly preserved fossils, possibly thin shelled brachiopods, ostracodes, and sponge spicules, occur in the dolostones and chert. Spherical ghosts in the chert may represent radiolarians.

Member 3W

Member 3W extends from AV 1 320 m - 456 m, AV 2 0 m - 165 m, and AV 4 0 m - 14.5 m. The deposits are dark grey to black, thin to medium bedded, fine wavy-planar laminated, argillaceous micrite or medium crystalline bioclastic sparite. Very thin chert lenses are abundant in the lower part of the member. Thin shale beds and interbeds are common. The beds lowest in argillaceous content are more resistant, commonly nodular due to differential compaction. Partial dolomitization is common within beds.

Samples with abundant pellets occur at AV 1 320 m, 430 m, and the lower 10 m of AV 2. The pellets commonly occur in laminae interlaminated with micrite or spar. A horizon at AV 1 347.5 m contains randomly oriented bioclasts, wavy-bedding, and possibly rip-up clasts. Other such horizons occur above AV 1 366.5 m. Fossils within the micrite beds are generally thin shelled and oriented parallel to bedding. No bioturbation is evident, though micro reworking on bedding planes could be present.

Member 1D

Member 1D extends from AV 1 456 m - 566 m, AV 2 165 m - 239 m, and AV 4 14.5 m - 126 m. The member consists of dark grey to black, yellow-brown weathering, very thinly bedded, finely laminated, recessive, platy, calcareous shale. Thin bedded argillaceous micrite occurs at rare horizons, becoming more common toward the top of the member. A limestone bed at AV 1 480 m is faintly laminated, containing compacted quartz lined burrows.

Member 2D

Member 2D is represented at AV 1-2, AV 4, AV 5, and AV 6. The sequence at AV 1-2 is relatively thin, AV 1 556 m - 601 m, and AV 2 239 m - 287 m. The sequence is thicker at AV 4 (126 m - 272 m), AV 5 (0 m - 224 m), and AV 6 (0 m - 260 m). At AV 1-2 deposits consist of massive, thick bedded, resistant, medium grey, coarse grained, bioclastic micrite and sparite, alternating with black, thin bedded, recessive, argillaceous micrite. The beds are similar at AV 4, but the beds are thicker and dominated by argillaceous micrite.

Member 2D at AV 5 and AV 6 can be divided into three submembers, a lower limestone (AV 5 0 m - 70 m, AV 6 0 m - 82.5 m), middle shale (AV 5 70 m - 189 m, AV 6 82.5 m - 233 m), and upper limestone (AV 5 189 m - 224 m, AV 6 233 m - 260 m). The lower limestone is thin to thick bedded, resistant, medium to dark grey, bioclastic micrite and sparite. Some recessive, thin bedded, argillaceous micrite and shaly horizons occur. At AV 6 the lower limestone is more argillaceous. The bioclastic units commonly contain lithoclasts of argillaceous micrite, typically chaotically oriented.

The shale unit is dark grey to black, very thin bedded, laminated, calcareous and fossiliferous. Bioclastic micrite beds are rare, but present throughout the unit. The shale grades into the overlying limestone.

The upper limestone is composed largely of medium to dark grey, thin to medium bedded, bioclastic micrite and sparite, with some interbedded calcareous shale. The limestone beds are resistant, fossiliferous, and partially dolomitized. The bioclasts and lithoclasts in the sparites are chaotically oriented. AV 5 200 m contains small unabraded pelecypod valves, oriented convex-up, in numerous little patches.

Member 3D

Member 3D consists of massive, light grey, crystalline dolostone, used as a marker to end the sections. A black, thin bedded, argillaceous micrite and shale horizon was measured at AV 2 327 m - 332 m. This horizon is bioclastic and highly burrowed. Dolostones continue above this unit. Fossil remnants indicate that the dolomite is secondary.

2.3.2 Paleontology

Faunal groups and ranges generally correspond to the lithologic members, commonly reflective of the depositional environment. The lithologic members presented are similar to the Grand Cycles proposed by Chatterton and Perry (1983) for lithofacies and trilobite biofacies of the proximal AV sections.

Fauna - Member 1W

The lowest Silurian fossils occur at, or just above, the Ordovician-Silurian boundary (AV 4B 111.0-111.6 m): articulate brachiopods, bryozoans, conodonts, rugose and tabulate corals, ostracodes, rostroconchs, and trilobites. At AV 4B 111.6 m the first characteristic Silurian conodont (*Ozarkodina hassi*) occurs. Inarticulate brachiopods, ostracodes, and sponge spicules are also common. The fauna up to AV 1 95 m and AV 4B 128.5 m contains only thin shelled brachiopods, small ostracodes, and trilobites. AV 1 95 / 95.5 m contains a sparse, but diverse fauna: bryozoans, conodonts, crinoid

ossicles, gastropods, ostracodes, radiolarians, sponge spicules, and trilobites. Inarticulate brachiopods are relatively abundant. From AV 1 95.5 m to 124.5 m inarticulate brachiopods, conodonts, and ostracodes occur in small numbers in most of the sampled horizons. Graptolites are common at AV 1 97.5 m and 102 m.

The fauna from AV 1 124-124.5 m is diverse. Conodonts, ostracodes, and radiolarians are common. Other groups present are brachiopods, crinoids, small gastropods, graptolites, sponge spicules, and trilobites. The remainder of Member 1W is largely unfossiliferous. Samples from AV 1 145 m and 165 m contain conodonts and sponge spicules. Ostracodes and trilobites are present at AV 1 145 m; inarticulate brachiopods, graptolites, and radiolarians occur at AV 1 150 m and 165 m.

Odontopleurid trilobites were described by Chatterton and Perry (1983) from Member 1W. Four odontopleurid species are common in samples collected from AV 1 84.5 m - 101.75 m, with one species of *Leonaspis* particularly abundant.

Fauna - Member 2W

Member 2W is mostly crystalline dolostone and chert. The source of chert is biogenic silica from radiolarians and sponge spicules. The only identified fossils are poorly preserved; trilobite fragments (?) from AV 1 185 m, sponge spicules from AV 1 230 m, and brachiopods and ostracodes from AV 1 290 m. Spheres within the chert may be radiolarian ghosts.

Fauna - Member 3W

Samples from the lower 25 meters of Member 3W (AV 1 320 m -346 m, AV 2 0 m - 25 m) are characterized by conodonts and trilobites. Some radiolarians occur; inarticulate brachiopods and conulariids are common. AV 1 347.5 m contains bryozoans, conodonts, crinoids, gastropods, ostracodes, and trilobites. The sequence to AV 1 395 m is largely unfossiliferous, with the exception of AV 1 369 m (see Chatterton and Perry, 1983, 1984). Conodonts, ostracodes, and trilobites do occur in other horizons, but are generally rare. From AV 1 400 m to the top of Member 3W conodonts occur in all the samples. Ostracodes and trilobites are rare to abundant. Inarticulate brachiopods and conulariids are common, some articulated brachiopods and cephalopods occur locally.

Radiolarians are common at AV 1 430 m. Bryozoans occur at AV 1 450 m.

Seventeen species of odontopleurid trilobites and twelve species of cheirurid trilobites were identified from Member 3W, concentrated in horizons between AV 1 320 m - 346 m, 411 m - 421 m, and 455 m - 460 m (Chatterton and Perry, 1983, 1984). Lenz (1977) and Copeland (1978b) identified brachiopods and ostracodes from the lower 10 m of AV 4 (Avalanche Lake 675-685 ft.). Six species of brachiopods and four species of ostracodes were listed.

Fauna - Member 1D

Member 1D is a dark grey shale with rare, thin bedded, argillaceous micrite horizons. A limestone horizon at AV 1 480 m yielded articulate brachiopods, conodonts, ostracodes, and trilobites. The bed was laminated and burrowed. Fish plates, oriented convex up, are abundant at AV 2 203 m, inarticulate brachiopods and conulariids are also common. Conulariids and graptolites are common in various horizons.

Fauna - Member 2D

Member 2D has only scattered conodont collections. At AV 1 and AV 2 the horizons vary from biostromal and bioclastic beds to argillaceous micrite. The lower six meters of Member 2D at AV 2 is locally biostromal, containing tabulate and solitary rugose corals, sponges, and stromatoporoids. The associated fauna contains brachiopods, conodonts, crinoids, and trilobites. The fauna from the same interval at AV 1 is less abundant, dominated by brachiopods and crinoid debris. The remainder of Member 2D at AV 1-2 contains articulate brachiopods, inarticulate brachiopods, bryozoans, corals, abundant crinoid debris, fish plates, and trilobites.

Samples collected from AV 4 contain articulate brachiopods, inarticulate brachiopods, conodonts, fish, ostracodes, and trilobites. Rostroconchs from Member 2D AV 1-2 and AV 4 were described by Johnston and Chatterton (1983). Odontopleurid and cheirurid trilobites were described from the same horizons by Chatterton and Perry (1983, 1984). Articulate brachiopods and ostracodes were described from samples collected from approximately AV 4 120-130 m (Avalanche Lake 300-330 ft.) (Lenz, 1977; Copeland, 1978b). Thirty species of brachiopods and twenty species of

ostracodes were identified.

Member 2D at AV 5 and AV 6 is divided into three submembers. The lower limestone member contains articulate brachiopods, bryozoans, tabulate and rugose corals, crinoid debris, ostracodes, and trilobites. In the upper part of this member, fish plates are abundant, commonly oriented convex-up.

The middle shale unit is generally poorly fossiliferous, but contains articulate and inarticulate brachiopods, conulariids, fish plates, graptolites, and nautiloids. *Lingula* sp. and their burrows occur at some horizons. Micrite beds contain brachiopod, crinoid, and trilobite debris.

The upper limestone unit is largely bioclastic. Clasts include brachiopods, crinoids, rugose corals, fish plates, gastropods, ostracodes, stromatoporoids, and trilobites. A micrite bed at AV 5 200 m contains convex-up oriented pelecypod valves. Conodonts are common.

Fauna - Member 3D

Member 3D is largely coarse crystalline dolostone. Crinoid ossicles, megalomid pelecypods, and pentamerid brachiopods are present. A micrite and shale unit at AV 2 331 m contains *Lingula* sp., their burrows, articulate brachiopods, bryozoans, and conodonts.

2.3.3 Environment of Deposition

This region has been described as the area of basin-shelf transition based on the interfingering of shales of the Road River Formation and carbonates of the Whittaker Formation and Delorme Formation (Gabrielse, *et al.*, 1973; Lenz, 1977)

The argillaceous limestone, chert, and shale sequence is similar in lithology to deep-water limestones described by Wilson (1969). Limestone deposited on the lower slope or basin is distinctive, typically dark, homogeneous or laminated, lime mudstone or micropelletal grainstone. Deposits are typically thin to medium-bedded. Dark shale and/or chert are commonly interbedded with the limestone. The faunas in Paleozoic

deep-water limestones are largely pelagic: cephalopods, graptolites, and radiolarians, with some other forms; pelagic or benthic gastropods and sponge spicules being the most common. Upward coarsening cycles from thin shales to fine grainstones are typical of deep-water limestones. These sequences can be 3 to 12 m thick, indicative of periods of shallowing (Wilson, 1969). Deep-water limestones have been described from the Great Blue Formation, Mississippian, Utah (Bissell and Barker, 1977), and the Lodgepole Formation, Mississippian, Montana (Smith, 1977). The limestones have similar lithologies and faunas compared to the AV sections.

Gravity flow deposits are also common in deep-water limestones. Deposits can consist of large shelf derived lithoclasts, carried by debris flows, to fine grained turbidites (Cook, *et al.*, 1972). The bioclastic gravity flow deposits of the AV sections are similar to the flow progressive turbidite sequence proposed by Davies (1977) from the Hare Fiord Formation, Mississippian-Permian, Northwest Territories. Deposits termed "flaser breccias", consisting of bioclasts and deformed lithoclasts, and more distal crinoid turbidites, dominated by shelly material, are lithologically equivalent to deposits described from the AV sections. Gravity flows commonly form from slumps or failure of build-ups, initiated by earthquakes or storms.

The possibility of oxygen stratification and its effects in an enclosed basin were discussed by Byers (1977), and a general model was proposed. Oxygen depleted water will develop in a basin that stratifies. If the basinal waters transgress onto the shelf, with or without a rise in sea level, dysaerobic or anaerobic conditions will occur. Such an occurrence is indicated by a reduction in shelly organisms in a dysaerobic environment, or an elimination of all metazoans by an anaerobic environment.

Biologic facies and depth associations have been proposed for Silurian conodonts, but regional variation and the uncertainty of the conodont animal's life mode make their application questionable (see Paleoecology). Silurian-Devonian benthic associations were proposed by Boucot (1975). These assemblages are largely based on brachiopod communities. While the brachiopod communities can vary regionally, the life mode of brachiopods is better known than that of the conodontophorids.

Six benthic assemblages and a more distal community were proposed by Boucot (1975) as representative of benthic faunas and environments in the Silurian and Devonian. The assemblages are further associated with the relative energy of the environment. Members 1W through 2D fit into the classification of the quiet-water environment of the lower-middle Llandovery and upper Llandovery-Ludlow assemblage scheme. Member 3D is classified as a rough environment (Figs. 6, 7). Quiet water deposits are indicated by articulation of the brachiopod shells, rough water (presumably high energy) by reworking of the shells (Boucot, 1975). From most distal to shoreward, the communities found at the AV sections are: the Pelagic Community, characterized by graptolites, radiolarians, other pelagic organisms, and sponge spicules; Benthic Assemblage 6, characterized by a general lack of shelly material, but some graptolites and trilobites; Benthic Assemblage 4-5, characterized by a diverse brachiopod fauna of the *Dicaelosia-Skenidiodes* Community, which are generally small and thin shelled, and trilobites; and Benthic Assemblage 3, the depth limit of corals and stromatoporoids, characterized by the *Linoporella* Community in quiet water, and the Pentamerinid Community in higher energy conditions.

Interpretation

The latest Ordovician and earliest Silurian was a period of glaciation in the southern continents. Sea level fluctuated greatly in this time, resulting in widespread unconformities between Ordovician and Silurian strata (Berry and Boucot, 1973; Lenz, 1976, 1982). No major disconformity is evident at the Ordovician-Silurian boundary section at AV 4B, though a distinctive irregular bedding plane or possible erosional surface occurs at AV 4B 111.0 m, on the top of a unit of platy limestone containing the trilobite *Cryptolithus* (apparently below the Ordovician-Silurian boundary). The beds overlying this break are fossiliferous micrite (AV 4B 111.5 m). At the base of the Silurian, autochthonous halysitid and solitary rugose corals, articulate and inarticulate brachiopods, bryozoans, conodonts, ostracodes, and trilobites occur in dark grey-black argillaceous micrite. The corals and bryozoans represent the basinward extent of a shallow-water fauna during a lowering of sea level. Other fossils at this interval reflect the quiet water sediments.

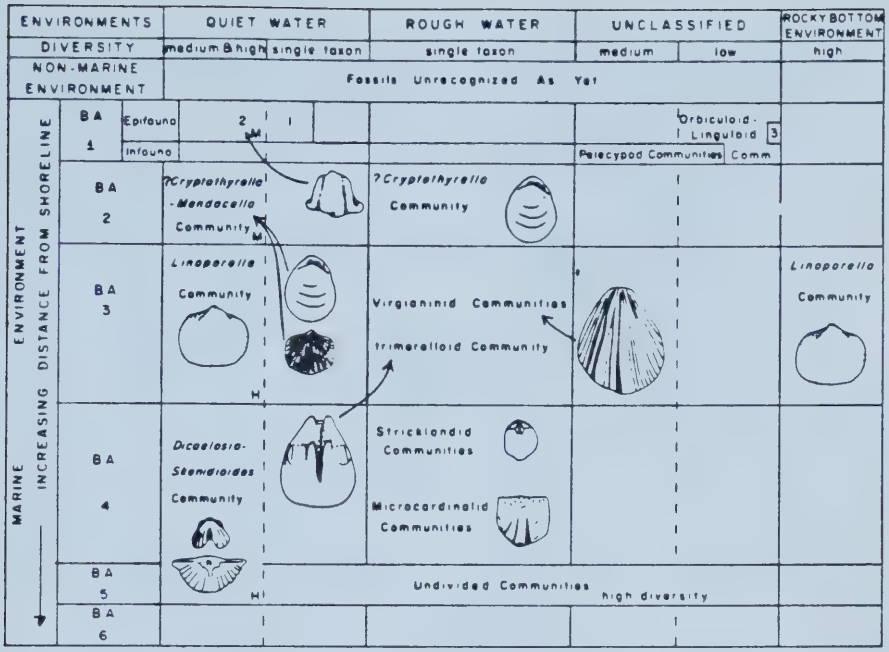

Figure 6 Lower and middle Llandovery level bottom, non-reef communities (North Silurian Realm).
1 = Rhynchonellid Community; 2 = Homolanotid(sic)-*Plectonotus* Community;
3 = *Arthrophycus* Community, M = medium diversity; H = high diversity. (From Boucot, 1975.)

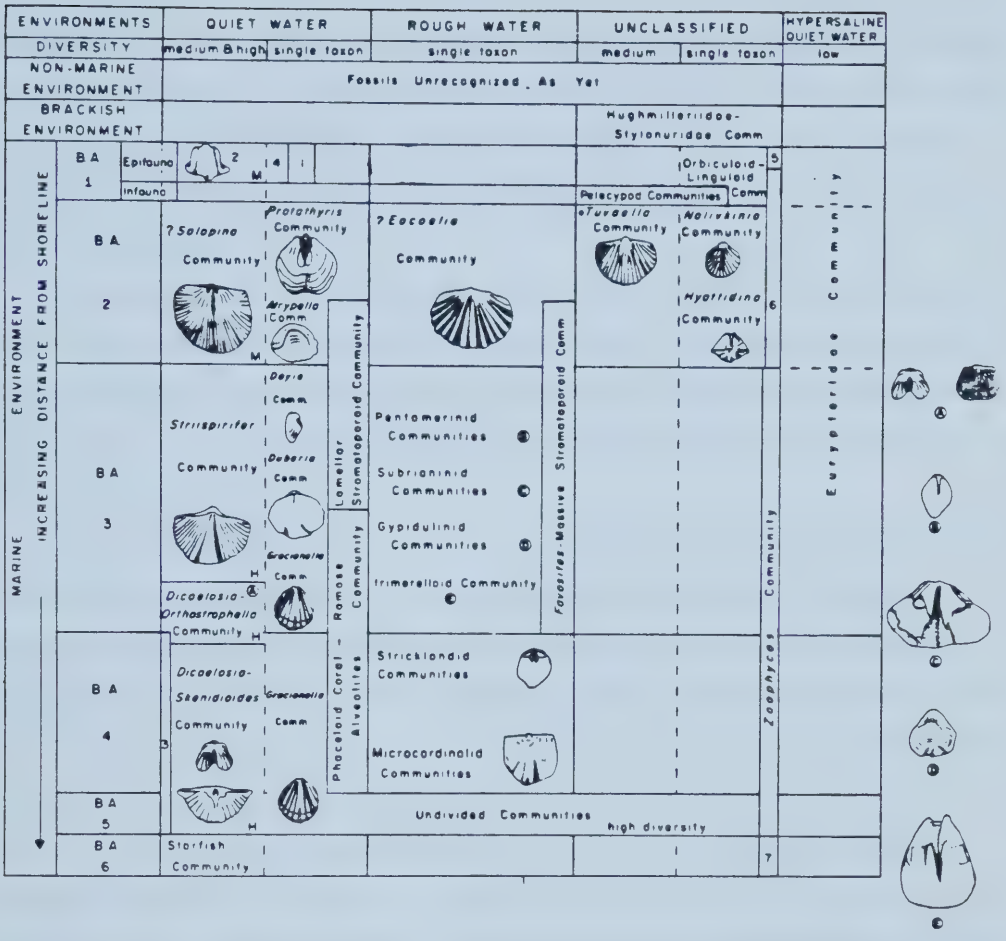

Figure 7 Upper Llandovery - Ludlow level-bottom, non-reef communities (North Silurian Realm including Uralian-Cordilleran plus North Atlantic Regions of the Late Silurian). Reef complex of communities occurs in about B. A. - 3 position.
• = Mongolo-Okhotsk Region; 1 = Rhynchonellid Community;
2 = Homolanotid(sic)-*Plectnotus* Community; 3 = Orthoceroid Limestone Community;
4 = Stromatolite Community; 5 = *Scolithus*(sic) Community; 6 = *Cruziana* Community;
7 = *Nereites* Community; M = medium diversity; H = high diversity. (From Boucot, 1975.)

The ostracodes are morphologically similar to modern deep-water forms. Small thin-shelled ostracodes are indicative of deep-water environments (Benson, 1961). Articulation indicates that they were deposited in quiet water without reworking. Small inarticulate brachiopods, when not found associated with their burrows, are interpreted as being pelagic. Ziegler, *et al.* (1968) reported small inarticulate brachiopods and *Lingula* as common in graptolitic deposits. They were interpreted as larval stages. Another possibility is that they were epiplanktic, attached to algae or other floating debris, later falling into deep-water.

The boundary horizon is in an area of faunal mixing. Corals, usually diagnostic of shallow-water conditions, occur in deeper water sediment with deep-water microfossils. The corals may have colonized the substrate during a period of low sedimentation (providing the suitable substrate), only to be buried by dark argillaceous micrite with an associated deep-water fauna.

From the Ordovician-Silurian boundary to AV 1 95 m the sediment is dark colored, finely laminated argillaceous micrite. The fauna is mixed, consisting of pelagic and deep-water benthic forms, assignable to Benthic Assemblage 5 or 6. The dolomite replaced gypsum crystals at AV 1 95 m represent a period of supersalinity in the bottom waters. This could be the result of a basinal high-density water layer transgressing onto the slope / shelf, or a local restriction of circulation on the shelf / slope. A rise in sea level could reduce mixing and create density stratification in the Selwyn Basin, which was a semi-restricted trough. A combination of sea level rise or restriction would result in a thickening of the basinal unmixed layer. Supersaline conditions could also develop where a local restriction reduced bottom-water mixing. A bioherm, raised slump block, or undulatory bottom, could restrict mixing. The reduced benthic fauna in this horizon, and the beds above, could be the result of fluctuating or unfavorable water conditions.

AV 1 95 m to 165 m is a continuation of dark, thinly laminated, argillaceous micrite deposition. The fauna is largely limited to pelagic species and deep-water forms. Chatterton and Perry (1983) reported a low diversity of odontopleurid trilobites from a narrow horizon around AV 1 100 m. Graptolites, radiolarians, sponge spicules, deep-water ostracodes, and the trilobite fauna indicate an assignment of this fauna to Benthic Assemblage 6 or deeper. The conodont collection from AV 1 124 m is

dominated by fully developed dwarf elements. A reduction in size of an organism is commonly an indication of adverse conditions, such as depletion of oxygen or change in salinity (Boucot, 1981). This population, followed by a normal population of the same community at AV 1 124.5 m, indicates a period of low oxygenation or encroachment of supersaline basin waters. A normal benthic fauna, including brachiopods and trilobites, occurs at AV 1 124.5 m, but not at AV 1 124 m.

Chert nodules and lenses are common through this sequence. The chert is black, probably forming from a biogenic siliceous source. Dolomitization limited fossil collections from the upper horizons.

The environment for Member 1W is interpreted as a slope / deep shelf which was receiving fine clastic and carbonate sediment. Except for the basal Silurian, the fauna indicates deep quiet water, below the level of organic reef build-up. Episodic variations in mixing in the Selwyn Basin caused rises in anoxic and / or supersaline waters, reducing benthic populations and forming evaporite environment minerals. Fluctuations in sea level and / or changes in sediment rate, as indicated by Wilson (1969), are evident by minor coarsening upward cycles. The sediment was probably anoxic, indicated by the lack of bioturbation, and the presence of pyrite and hydrogen sulfide in the samples.

Member 2W is composed of dark, thinly laminated, thin beds of calcareous dolostone, cherty dolostone, and dolomitic chert. The only evident fossils are thin shells and possibly radiolarian ghosts. The laminations preserved in the dolostone, and color of the beds, indicate formation in an environment similar to the underlying beds. The argillaceous micrite has been replaced by dolomite. The formation of chert was probably due to a proliferation of siliceous material, radiolarians and / or sponge spicules, which are preserved in the underlying and overlying beds, commonly preserved by pyrite replacement. Local erosion of chert beds could be due to scour by contour or turbidity currents, or solution. Erosion by turbidity flow is the most likely process as shallow-water material is present in the form of crinoid ossicles, and gravity flow deposits are common in other horizons. Contour currents are unlikely because of the absence of current structures in other deposits and evidence suggesting little bottom-water mixing. Solution of the chert beds may occur after prolonged exposure,

but the mechanism for such an occurrence would require extremely basic conditions, which do not appear to have prevailed in this situation.

The environment of Member 2W is characterized by an abundance of siliceous organisms. Argillaceous micrite was altered to dolomite, the chert probably formed from solution and reprecipitation of radiolarians and sponge spicules. Dark cherts from the Silurian-Devonian Caballos Formation, described by McBride and Folk (1977), were interpreted as forming from biogenic silica (radiolarians), in an association with terrigenous clays, carbonate, and organic material. McBride *in* McBride and Folk (1977), favored deep-water formation for the cherts. Davies and Supko (1973) noted, in reference to Jurassic and younger sediments, that chert beds are largely associated with pelagic sediments. Scholle, *et al.* (1983) favored rapid formation of sedimentary chert in calcareous environments. Biogenic opal is unstable, and carbonate has an accelerating effect on chert formation.

Member 2W is interpreted as a deep-water chert forming from pelagic material and sponge spicules in a basin-slope environment. Hemipelagic carbonate material dominates over shale, indicating a sedimentation rate higher than that of the basinal shales and cherts of the Road River Formation.

From the top of the chert sequence to the base of the Delorme Formation, the beds are dark grey, argillaceous micrite with shaly and cherty horizons grading into more fossiliferous and sparry limestone.

The lower 25 m contains a pelagic fauna of conulariids, inarticulate brachiopods, and radiolarians, with conodonts and trilobites. This fauna occurs in interbedded, dark grey, argillaceous micrite, locally pelletal, and calcareous shale. This interval represents a relative shallowing from the pelagic cherts, although within the deep-water zone corresponding to Benthic Assemblage 6.

From AV 1 346 m to AV 1 395 m, and the corresponding interval from AV 2, the beds are dark, argillaceous micrite, thin beds of calcareous shale, and intervals of crinoidal sparite. A sparse fauna occurs in the finer grained material: brachiopods, conodonts, ostracodes, and trilobites. The crinoidal sparites, attributed to turbidity flows originating on the shallow-shelf, contain brachiopods, bryozoans, conodonts, corals, crinoids,

ostracodes, and trilobites. The degree of abrasion indicates transport was short, or in a dilute flow of low energy, although a gravity flow can incorporate material in the flow as it moves down slope (Cook, *et al.*, 1972). The reduction in pelagic organisms, and the presence of only minor chert horizons, indicates an increase in energy and general shallowing. Bedding planes are more evident and sharper than in the lower beds, indicating minor bioturbation (Boucot, 1975), or a response to increased wave / current agitation. In contrast, intrasediment bioturbation is not evident, and pyrite and hydrogen sulfide are present in the deposits. These beds are interpreted as having been deposited in the deep shelf environment. Minor sea level fluctuations are indicated by small cycles of shale and limestone.

The upper portion of Member 3W is similar to the underlying deposits, with a reduction in the shaly beds. The sequence consists of a dark, argillaceous micrite with local bioclastic horizons. Pelagic forms and benthic species of articulated brachiopods, conodonts, conulariids, inarticulate brachiopods, ostracodes, radiolarians, and trilobites are common, indicative of Benthic Assemblage 5 and 6. Bryozoans, corals, and crinoids occur in bioclastic beds, interpreted as turbidity flow deposits. The deposits are locally pelletal, although they contain pyrite and hydrogen sulfide, indicating an anoxic sediment. One pelletal horizon contains radiolarians, indicating the bed was deposited during a period of low sedimentation, allowing pellets and radiolarians to accumulate. In this interval pelagic material is present, suggesting slope / shelf deposition.

The overall picture of deposition of Member 3W is of shallowing upward from the chert, represented by argillaceous micrite. The micrite beds are overlain by micrites associated with a shelly fauna, indicating deposition on the shelf. The middle portion of the member has a sparse fauna, and is more argillaceous, indicating an interval of deepening. The upper portion is similar to the lower, containing a mixed fauna diagnostic of the slope / shelf. The deposits throughout Member 3W lack high energy sedimentary structures and endobenthic burrowing, and contain pyrite, indicating low energy and an anoxic sediment. Some bioclastic horizons are the result of gravity flows of material built-up on the shallow shelf (banks?), or material carried off shore by storms.

A series of shallow water pulses and general shallowing through this sequence is inferred through trilobite lineages and morphological change (see Chatterton and Perry,

1983), and coarsening upward cycles, with an increase in bedding thickness near the top of the member.

Member 1D is a thick unit of dark grey, finely laminated, calcareous shale, interbedded with, thin, argillaceous micrite, which becomes more common upward. The shale contains a pelagic fauna of conulariids, graptolites, and inarticulate brachiopods. Rare limestone beds contain articulate brachiopods, conodonts, fish plates, ostracodes, trilobites, and endobenthic burrows. The shale apparently represents a major increase in water depth, decreasing the input of carbonate material into the deep shelf, or an environmental change causing the same decline in sedimentation. The limestone beds are gravity flow deposits, or represent periods of higher carbonate input when the bottom conditions were suitable for benthic organisms, possibly during drops in sea level. The member was deposited mainly in a slope environment, with some periods of shelf sedimentation or aerobic periods on the slope, becoming shallower and with an increase in carbonate sediment near the end of Member 1D deposition.

The deposition of Member 2D at AV 1-2 represents a period of shallowing. The sediments are thick bedded, bioclastic micrite and spar, locally biostromal. The fauna is characteristic of Benthic Assemblage 3 or 4, composed of articulate brachiopods, corals, crinoids, sponges, stromatoporoids, and trilobites. The more argillaceous horizons contain a deeper water fauna. The sequence at AV 4 is a thicker, argillaceous equivalent to AV 1-2. The fauna is typical of Benthic Assemblage 4 to 6. Brachiopods collected from this section (AV 4 120-130 m) were assigned to the *Dicaelosia-Skenidiodes* Community (Lenz, 1977), representative of Benthic Assemblage 4 and 5. Member 2D at AV 1-2 is a shelf sequence, deposits at AV 4 are thicker, representing deeper water shelf / slope deposits.

Member 2D at AV 5 and AV 6 is a thick section, laterally equivalent to AV 1-2 and AV 4. The lower limestone is dark, thin to thick bedded, bioclastic micrite, with sparite and shale horizons; AV 6 contains more argillaceous material. The fauna is assignable to Benthic Assemblage 4. Rare corals represent shallower periods. Shale beds indicate a decrease in carbonate material during deeper water. The lower limestone represents a

deep shelf deposit.

The middle shale unit represents an increase in water depth across AV 5 and AV 6, and deposition of basin shales. The fauna is of pelagic origin: conulariids, fish plates, graptolites, inarticulate brachiopods, and nautiloids, except for *Lingula sp.* and burrows. The *Lingula* are not pelagic larval forms, as they are infaunal burrowers. *Lingula* are usually inferred to occur only in water depths less than 100 m (Ferguson, 1963; Ziegler, *et al.*, 1968), but *in situ* lingulids have been reported from deep-water carbonate strata (outer shelf or upper-slope deposits) of Ordovician age in Newfoundland and Québec (Pickerill, *et al.*, 1984). Bioclastic micrite beds, formed from gravity flows, contain disoriented shallow-water forms: articulate brachiopods, crinoids, and trilobites. This sequence is interpreted as basin shales deposited on the slope.

The upper limestone represents a shallowing sequence from the underlying shale, with an increase in gravity flow deposits or reworking of in-place bioclastic and carbonate sediments. Beds are bioclastic, commonly with chaotically oriented fossils of Benthic Assemblage 3. Brachiopods, corals, crinoids, fish plates, gastropods, ostracodes, pelecypods, stromatoporoids, and trilobites were present in one sample. Beds of small pelecypods, oriented convex up, in a matrix of dark, faintly laminated, argillaceous micrite, indicate storm deposits of shallow-water material that have been transported into deeper water. The absence of pyrite, common in the lower members, indicates an increased oxygenation of the sediment. The upper beds are more dolomitic. This sequence is interpreted as having been deposited on the shelf, in deep-water, though within the zone of periodic bottom mixing.

Member 2D represents a lateral change from basin to slope to shelf within five kilometers, and a vertical change from shallow to deep to shallow at AV 5 and AV 6. AV 1-2 was the site of largely shelf sedimentation, becoming more argillaceous in the deeper water horizons. AV 4, AV 5, and AV 6 were more distal, though periods of shelf sedimentation are evident in the lower and upper submembers. Gravity flow deposits are a major source of sediment at AV 5 and AV 6. Time lines could not be accurately established from conodonts to lend evidence for a topographic boundary between the shelf and slope. The thickness of the member corresponds to a change, reflective of topographic relief or sedimentation rates.

The dolostones of Member 3D are not distinctive of any environment, although they suggest a shallow-water sequence. Preserved fossils, crinoids, pentamarids, and megalomid pelecypods indicate shallow, rough water conditions, assignable to Benthic Assemblage 3. In-place *Lingula* in a shale sequence, containing conodonts, is not indicative of a specific environment. Although lingulids are usually associated with fine clastic material, they have been found in other deposits (Pickerill, *et al.*, 1984).

This sequence is interpreted as a shelf deposit, subtidal, within the zone of mixing and above the storm wave base. Dolomitization was secondary. The succession in Member 3D represents a movement of the slope / shelf transition to the west, away from the AV sections, and a continuation of shelf sedimentation in the area.

Discussion

The shelf margin during most of the AV sequence deposition was not distinguishable by a sharp bathymetric break. Instead of an abrupt change in slope in this region, the shelf continued into the basin in a shallow slope. The margin is therefore determined by the change in lithology and fauna.

Because of the low relief, even minor changes in sea level caused significant changes in sedimentation and the benthic environment, resulting in deposition of diagnostic sediments and associated fauna. Major rises in sea level resulted in a transgression of shale deposition and anoxic bottom conditions. Drops in sea level are indicated by a progradation of shelf conditions. Minor fluctuations are represented within the major trends by slight reversals in sedimentation and cyclic deposits. A transition between basin-type and shelf deposits, "slope" sedimentation, is represented by dark argillaceous micrite with a mixed fauna (Benthic Assemblage 6). True basin deposition was limited to the central Selwyn Basin. The shelf is interpreted as occurring in areas of micrite and sparite deposition with shelly fossils (Benthic Assemblage 3-5). Basin-like deposits are indicated by shale, thick cherts, pelagic organisms, and unfossiliferous horizons. The slope deposits are intermediate to the two areas. These facies assignments are approximations because of the nature of the AV shelf / slope transition and its variation in position through time.

The low number of gravity flow deposits in the lower members may be due to the low relief of the shelf-basin transition or by-pass sedimentation. By-pass sedimentation results where gravity flows occur, but continue through a region, depositing sediments in distal locations. In this situation, hemipelagic and pelagic material will dominate in a region proximal to the depositional area of the gravity flows. The depositional model of McIlreath and James (1979) illustrates this sequence.

Members 1W-3W and Member 1D were deposited in the area of the slope / shelf transition, the period of greatest shallowing occurring at the Ordovician-Silurian boundary. Sedimentation varied between deep-shelf and basin-slope environments throughout Member 1D, the margin fluctuating through the sections.

In Member 2D shelf build up may have defined a topographic shelf break. The middle shale unit of AV 5 - AV 6 does not reach AV 4, while AV 1-2 is a shelf deposit with only minor shale interbeds. Through the depositional period of Members 2D and 3D, the shelf margin moved to the southwest, forming a vertical shale, argillaceous limestone, limestone, dolostone sequence. The dolostone of Member 3D, of shelf origin, marks the top of the AV sections.

3. CONODONT FAUNA

3.1 Introduction

The conodonts collected from the Avalanche Lake sections range in age from Late Ordovician (McCracken and Nowlan, 1984) to Ludlow-Pridoli in age. Only the Silurian conodonts will be discussed. Nineteen multielement genera, two new, and fifty seven multielement species and subspecies, nineteen new, were identified, as well as six forms termed "genus and species indeterminate". Pectiniform and ramiform elements compose 68% of the collection, simple cones 32%. Numerically, *Panderodus* dominates the collection, with 25%, *Oulodus?* composes 17%, *Pterospathodus* 16%, and *Ozarkodina* 11%. The remainder of the genera make up the other 31%, none greater than 6% of the total element number. The total number of elements of each species in a collection may not provide a true picture of the relative abundance of conodont taxa during life. Different conodont apparatuses contained different numbers of elements. Using a specific element such as the Pa, Pb or Sa as an indicator of species abundance is more realistic, but taphonomic processes bias the collection, favoring the species with more robust elements. Differential transport and other factors prevent anything but a rough estimate of the conodont population. Using the Pa elements though, and dividing the total numbers of each genus by two (the assumption is that each apparatus had two Pa elements), the relative generic distribution of pectiniform and ramiform element bearing genera is 42% *Pterospathodus*, 15% *Ozarkodina*, 10% *Astropentagnathus*, 9% *Apsidognathus*, 8% *Aulacognathus*, and 7% *Oulodus?*. This is a marked departure from the numerical dominance of *Oulodus?* elements, indicating a population dominance of *Pterospathodus* for the sections. The percentage of *Pterospathodus* relative to other genera would be higher if specimens only within its range were considered.

In the measured sections, conodonts are rarely abundant. Samples averaged 20 elements and fragments per kg of rock. Only five samples yielded more than 100 elements / kg. Diversity is generally high, though somewhat dependent on sample size due to the low abundance, with up to twenty three species in a sample. The average for samples that yielded conodonts was seven species. Sample size, locality, conodont fauna and numbers are listed in Tables 1-5 and in Appendix 2.

Table 1 Distribution of conodonts, Whittaker Formation, Member 1W, Avalanche Lake sections AV 1 and AV 4B.

Conodonts / Sample Locality		AV 1																					AV 4B					TOTAL
Number of Specimens		0	4	5	26	208	47	3	3	1	5	24	6	134	153	1	0	7	14	13	2	0		1	11	0	1	889
Mass (kg)		2.2	3.7	2.0	9.9	1.9	5.0	2.2	1.2	4.6	3.9	4.5	2.1	2.6	4.4	3.4	1.3	1.2	1.0	1.0	3.5	1.0		3.0	1.0	1.0	0.9	
		85	92	95	95.5	97.5	101	103.5	106.5	107	110	118.5	120	124	124.5	130	133	145	150	165	174.5	185		115	116	120	136.5	
Icriodella discreta	Pa			1																								1
	Pb?			1																								1
Distomodus kentuckyensis	Pa				1	2	7																					10
	Pb				2	3	2																					7
	M					3	2																					5
	Sc				1	4	2																					7
	Sb-Sa		1		1	9	4																					15
Distomodus - Icriodella (?)							6								2													8
Panderodus unicostatus					3	70	5	1	1					19	4													103
Panderodus spp				2	4							2			3			2						?1		1		15
Walliserodus sancticlairi					4	22	6								13										1			46
Walliserodus spp									1				1	20					3	1								26
Oulodus? fluegeli	Pa											3	1	7	11				1	2								25
	Pb													14	18				1	1								34
	M											8	2	10	27	1				2	1							51
	Sc											5	1	29	28				3	1								67
	Sb											1		9	7					1								18
	Sa												1	16	14					1								32
	'T'											1		1	12													14
Oulodus? kentuckyensis	Pa					3																						3
	Pb					4																						4
	M					2																						2
	Sc					20																						20
	Sb					3																						3
	Sa					5																						5
Oulodus? nathani	Pa						1																					1
Oulodus? spp			1		2	4	5			1				2	1				1	1	?1				1			20
Ozarkodina hassi	Pa					2												2							5			9
	Pb																	1							1			2
	M					2																						2
	Sc																	1							1			2
	Sb																								1			1
Ozarkodina oldhamensis	Pa										?1																	1
	Pb					1					1																	2
	M										1																	1
Ozarkodina n. sp. A	Pa				2																							2
	Sc				1																							1
	Sb				1																							1
Ozarkodina n. sp. B	Pa					2																						2
	Pb					2	1																					3
	M					1	1																					2
	Sc					5	3																					8
	Sb					2	1																					3
	Sa					1																						1
Ozarkodina spp	Pa																	1										1
	Pb														1													1
	Sc			1		2		1			1																	5
	Sb				1	1																						2
Dapsilodus obliquicostatus			2		3	30	1	1	1			3		7	8		2	2	3					1				64
Decoriconus fragilis						3						1			4				1									9
Gen. sp. Indet. A											1																	1

"T" = Transitional elements in the apparatus of *Oulodus? fluegeli*

Table 2 Distribution of conodonts, Whittaker Formation, Member 3W, Avalanche Lake section AV 1.

Conodonts		Number of Specimens	0	179	426	90	55	80	274	3	1	9	3	2	12	32	7	117	164	27	77	140	10	26	3	0	0	157	40	0	0	252	8	2389
		Mass (kg)		0 4	15 4	69 6	1 5	19 0	4 7	1 0	7 5	1 1	1 0	1 5	1 1	1 0	1 8	6 2	4 5	11 0	8 2	8 4	4 6	1 2	1 9	5 5	0 9	1 4	1 4	1 1	5 6	1 0		TOTAL
		Sample Locality / Av 1	300	320	336	340 B	341	346	347 5	366	370	376	385	395	401	405	411	414	417 5	418	419	421	430	434 5	440	441	445	450	453	455	456	460	480	
Curtoniodus curvulus	Pa				?1											1												4	1	5		1		13
	Pb																				1							3	2	16				22
	M				?1											?1												1		1				4
	Sc																											1		1				2
	Sb															1												2				1		4
	Sa				?2																							2		1				5
Apsidognathus tuberculatus	Pa_1				10			1	4								1		30	4	9	19						2		4		7		91
	Pa_2																		2		1	2												5
	Pb_1				1																	1												2
	Pb_2				7				2										4			2						2		2				19
	S				1				1										5		1	1						1				2		12
Apsidognathus n sp A	Pa_1																					5								1				6
Astropentagnathus irregularis	Pa_1			28	30	15	1																											74
	Pa_2			8	14	15	4																											41
	Pb_1			2	3	1																												6
	Pb_2				2	2																												4
	S			3	3	4	1																											11
Aulacognathus bullatus bullatus	Pa			8	7	4	1	1	1							1		1				2												26
	Pb			3	1	1		1											4		2	4	1									4		21
Aulacognathus bullatus n ssp A	Pa				2														3		2	6							2					15
Aulacognathus kuchmi	Pa								5																									5
Aulacognathus aff *A. latus*	Pa				1														2															3
Aulacognathus n sp A	Pa																		8	1														9
Aulacognathus n sp B	Pa																															7		77
Pterospathodus celloni	Pa			5	20	5	4	5	17							4	1	27	14		10	11												123
	Pb			10	12	4	2	7	6							4		6	8	2														61
	M			3		1										1		1																6
	S			2														1																3
Pterospathodus amorphognathoides	Pa				7			1	1	4									9			11										1		33
	Pb				14				1	14									8	1		8						4		17		11		78
	M				4				1	6									3			2						3		8		2		29
	S				2					4									2			1						1		4		4		18
Pterospathodus pennatus procerus	Pa			12	8	4	5	8	52							1	1				1							9		54		35		191
Pterospathodus pennatus n. ssp A	Pa																													10				10
Pterospathodus spp	Pa																				2	4		13					1					20
	Pb				4																	1		4					1					1
	M				3									1										1					1					6
New Genus A n sp A	Pa_1				4	2	2		2																									10
New Genus A n sp B	Pa_1																	?1	3															4
Distomodus staurognathoides	Pa							1	1									1	8	2	7	5										4		29
	Pb				3		1	1	2	?1								1	3	1	3	1										1		18
	M		1				2	1	6										1			3										3		17
	Sc		9	3			1	2	8									1	2			4										2		32
	Sb		2	1				2	2									1				3										1		12
	Sa			1					4							1		1	2	1	1	4									1			16
	-S																		1			5						1				6		13
Panderodus unicostatus				13	69	4	13		36			3	1	1	5	17	1	16	27	8	15	8	4		1			36	8	45		88	5	424
Panderodus sp				29	85		2	20	16		1		1					4	5			20		5				24	14	18				244
Belodella sp A				16				3												1	2				2			18	4	4				50
Walliserodus sp					12			4	3									2		1	1							3						26

Pb elements assigned to species of *Aulacognathus* are listed under *A.b. bullatus*

Pb, M and S elements of *P. p. procerus* and *P. p.* n. ssp A are listed under *P. amorphognathoides*

Table 2 cont.

Oulodus? flangeli	Pa			2	11	2	2					1																				18
	Pb			3	7	1																										11
	M			6	14	1	2																									23
	Sc			3	9	2	4																									18
	Sb			1	6																											7
	Sa			6	3	1																										10
	"T"				1																											1
Oulodus? n. sp. 1	Pa				1	1		18								1								1								22
	Pb							5	1																							6
	M							22								4								1								27
	Sc							11								3																77
	Sb				1	1		3								2																7
	Sa							8																								8
Oulodus? n. sp. 2	Pa															2	1							2								5
	Pb															2								6								8
	M															2	3							7								12
	Sc																						5									6
	Sb																							4								4
	Sa															1							3									4
	"T"															1	1	2						8								12
Oulodus? n. sp. C	Pa			2		?1																										3
	Pb			2		1																										3
	M					?1	1																									2
	Sc			3		2	2																									7
	Sb			2		2	1																									5
	Sa				1	2	1																									4
Oulodus? n. sp. D	Sc																										1					1
Oulodus? spp.	Pa																							1								1
	Pb											2			1		?1	1									2					7
	M				2			2								2	1	1		1				2			1					12
	Sc				5	4	1					1			3	4												11				29
	Sb							1				1				1								1			1	2				7
	Sa				1			1							1	1				1		1			2	1	2					11
Uzarkodina badra	Pa															1			6								3		8			18
	Pb															?1			5								2		4			12
	M																		1										1			2
	Sc																										2		10			12
	Sb			1														1		1					2			3				8
	Sa																												8			8
Uzarkodina gulletensis	Pa			?4																									73			7
	Pb			4	2														1		1						1					9
Uzarkodina spp.	Pa							3			1									1								1				6
	Pb			1				1	1										4	1							1		2			11
	M									1										1									1			3
	Sc			1				2																								3
	Sb																												3			3
	Sa													1					1													2
Dapsilodus sp.				3	5																			2						1		11
Decoriconus fragilis													2		2	22	1			1	2	3		8	3	4		5	2			55
Pseudooneotodus beckmanni					2			1											?1													4
Pseudooneotodus bicornis																												1	?1			1
Pseudooneotodus tricornis																1	1												5			7
Pseudooneotodus n. sp. A																					1											1
Spathognathodus n. sp. A s1																											1		3			4
Gen. sp. indet. C																2																2
Gen. sp. indet. D																						1										1

"T" = Transition elements in the apparatuses of the *Oulodus? flangeli* group

"J" = *"Johnognathus"* fragments and complete elements of *Distomodus staurognatoides*

Table 3 Distribution of conodonts, Whittaker Formation, Member 3W, Avalanche Lake sections AV 2 and AV 4.

Conodonts / Number of Specimens / Mass (kg) / Sample Locality		AV 2		3	119	94	50	182	284	284	55	209	54	179	8	AV 4	222	300	119	78	1	2241
				3.6	5.4	3.9	5.0	24.6	18.9	9.2	-	2.2	9.5	10.5	2.4		4.4	8.3	3.7	8.8	2.2	TOTAL
				6.5	9	11.5	13	17	47	63	127	152	156	157	160		0	1	5	12	14.5	
Carniodus carnulus	Pa											2		2			5	5	2			16
	Pb											11					13	8	5			37
	M																1	1				2
	Sc																6	2	1			9
	Sb																4	3	1			8
	Sa																1	1				2
Apsidognathus tuberculatus	Pa_1								2	5	9	6	1	3			9	18	6			59
	Pa_2									1		2						3	1			7
	Pb_1																	1				1
	Pb_2									2		6					1	9	3			21
	S									1				2			2		2			7
Astropentagnathus irregularis	Pa_1			14		9	58			12												93
	Pa_2			1		10	16			17												44
	Pb_1			3		1	2	1														7
	Pb_2			?1			?2			3												6
	S			3		1	3			1												8
Astropentagnathus aff *A. irregularis*	Pa_1				5																	5
Aulacognathus bullatus bullatus	Pa					1	13	1	12	3	4	1	5						3			46
	Pb			3		1	1		5			2							3			15
Aulacognathus bullatus n. ssp. A	Pa									2												2
Aulacognathus kuehni	Pa							5														5
Aulacognathus aff *A. latus*	Pa								2													2
Aulacognathus n. sp. A.	Pa								3													3
Aulacognathus n. sp. B.	Pa											5	1	1					4			11
Pterospathodus celloni	Pa			4		2	3	10	27	4												50
	Pb			1		1	1		20	2												25
	M			3			2		3	1												9
	S			2					5													7
Pterospathodus amorphognathoides	Pa							3		1		1				22	15					42
	Pb			2			4	5	3		10	4	2	2		26	7	5	4			74
	M			1			1	7			1	1	1			4	2		1			19
	S			4			2	2			2					4	2					16
Pterospathodus pennatus procerus	Pa			17		4	10	23	8		15	3	7			16	14	17	27			161
Pterospathodus pennatus n. ssp. A	Pa										38					34	32	8				112
Pterospathodus spp.	Pa							1							1							2
	Pb							1														1
New Genus A n. sp. A	Pa_1			7				1	21													29
	Pa_2								15													15
New Genus A n. sp. B	Pa_1										2											2
Distomodus staurognathoides	Pa			1	13			2	5	1	1	2	2			1	3	2	6			39
	Pb				2		2	2	7							2	2	1	1			19
	M			1	3		3	6	2	2		1				1	1	2	1			23
	Sc			1	10		2	16	3	1	2	2	3			2	3	3	2			50
	Sb			1	2			2			1					1			2			9
	Sa				2		3	5	2			2	2			1	2	1	3			23
	"J"								1	1	2	1				1	5	2	4			17
Panderodus unicostatus			2	10	5	11	23	52	94		70		66	4		36	78	16	1			468
Panderodus spp					4			20	10	6	4	16	6									66
Belodella sp. A					2			4								4	4					14

Pb elements assigned to species of *Aulacognathus* are listed under *A. b. bullatus*

Pb, M, and S elements of *P. p. procerus* and *P. p.* n. ssp. A are listed under *P. amorphognathoides*.

Table 3 cont.

Oulodus? fluegeli	Pa			2	5		1	3												11
	Pb			2	4	3	1													10
	M			7	11		5	1												24
	Sc			7	14	1	1	1												24
	Sb			4	2		1													7
	Sa			2	4	1	1													8
	"T"			1																1
Oulodus? n. sp. 1	Pa						6	3	1						2					12
	Pb						9	1	1						2					13
	M						17	4	4						1					26
	Sc						19	2	4											25
	Sb						9													8
	Sa						9								4					13
Oulodus? n. sp. 2	Pa									2		1			2	9	1			15
	Pb											1				8				9
	M									3		4				6	2			15
	Sc									3		4				8	1			16
	Sb									1					2	4				7
	Sa															1				1
	"T"																1			1
Oulodus? n. sp. C	Pa					1														1
	Pb						1	1												2
	Sc								1											1
	Sa					1	1													2
Oulodus? n. sp. D	Pa										1	2								3
	Pb?										1									1
	Sc										5	7								12
	Sa										1	?1								2
Oulodus? spp.	Pa				1											1		1		3
	Pb			?1	1		1				1				1					5
	M									1		1			1					3
	Sc			2	1	2	2			1		2					3			13
	Sb				1							2	1				1			5
	Sa			1						2	1	2								6
Kockelella ranuliformis	Pa																	1		1
Ozarkodina excavata excavata	Pa											6								6
	Pb											2						2		4
	M											2								2
	Sc											2						4		6
	Sb											2						2		4
	Sa											1						1		2
Ozarkodina hadra	Pa									1	1	10				6	14			32
	Pb									1						1	1			3
	M									1		2				1				4
	Sc									1						1				2
	Sb									1	1					3				5
	Sa											2				1				3
Ozarkodina gulletensis	Pa			1																1
	Pb			1																1
Ozarkodina n sp D	*Pa*										2	13				4				19
Ozarkodina spp.	Pa			1	1		2			1										5
	Pb			1	1		2			3		2			1					9
	M										2							3		5
	Sc						2				1							7		10
	Sb			3			1	2		1	1				1		2	4		15
Dapsilodus obliquicostatus		1																		1
Dapsilodus spp.							2				2							1		5
Decoriconus fragilis							4	3	8	6	5		3			4	17	3		53
Pseudooneotodus beckmanni							1	2												3
Pseudooneotodus bicornis																			1	1
Pseudooneotodus tricornis									8								2			10
Pseudooneotodus n. sp A																	3			3
Spathognathodus n sp A s f.												2								2
Gen sp. Indet D											1									1

"T" = Transition elements in the apparatuses of the *Oulodus? fluegeli* group
"J" = *"Johnognathus"* fragments and complete elements of *Distomodus staurognathoides*.

Table 4 Distribution of conodonts, Delorme Formation, Member 2D, Avalanche Lake sections AV 2 and AV 4.

Conodonts / Number of Specimens / Mass (kg) / Sample Locality		AV 2								AV 4									TOTAL
Number of Specimens			33	58	16	29	187	8			217	21	58	16	15	40	78	9	785
Mass (kg)			3.7	10.8	6.7	3.0	50.1	8.5			4.0	4.2	6.2	4.1	4.2	6.2	5.6	-	
Sample Locality			242	256	260	269	274	331			136	150.5	165	203	211	231	240	248.5	
New Genus B n. sp. A	Pa?										34								34
	Pb?										19								19
	Sc?		1			1	2				49								53
	Sb?					1					17								18
	Sa?										16								16
New Genus B? n. sp. B	Pa?										2								2
	Pb?										5								5
	Sc?										3								3
	Sc?										3								3
	Sa?										2								2
Panderodus unicostatus			16	35	5	16	90						6				4		172
Panderodus spp.							30	4			32	2							68
Oulodus? n. sp. F	Pa				1		3					2							7
	Pb						4					2							6
	M						3												3
	Sc				1		3					3							7
	Sb				2		2					2							6
	Sa				1		2					3							6
Oulodus? n. sp. I	Pa?															1			1
	Sc															5		1	6
	Pb																	1	1
Oulodus? spp.	Pa		?1				1				1				1				4
	Pb			?2			2				2		1		1				8
	M						2								1	1			4
	Sc				2		7	2			3				3			2	19
	Sb					2	3				2				1				8
	Sa			1		1	4									1			7
Kockelella absidata	Pa						1				1								2
	Pb						2												2
	M										1	2							3
Kockelella patula	Pa		4					1											5
Kockelella walliseri	Pa																1		1
Ozarkodina bohemica	Pa												15	1		8			24
	Pb												3	1		2			6
	M?												2	2		1			5
	Sc?												1			3			4
	Sb?												1			1			2
Ozarkodina confluens	Pa												?1	1	2	7	42		53
	Pa												1	1	1	4	6		13
	M												2			1	2		5
	Sc															2	5		7
	Sb																7		7
	Sa																4		4
Ozarkodina excavata excavata	Pa		2	2			4				4		9				2		23
	Pb		1	2			1				4		2						10
	M						1												1
	Sc			2			2				2		2						8
	Sb		1				2												3
	Sa						2												2
Ozarkodina n. sp. I	Pa			4							2	3	1						10
	Pb			3							5		4						12
Ozarkodina spp.	Pa		1		2	1		1			1		1	2	2			1	11
	Pb		2	1		3	1	1			2		1		2	1		3	17
	M				1														1
	Sc		2	3		4	2				2	2	3	5		1	3		27
	Sb						2				1		2	2					7
	Sa			1										1					2
Pseudooneotodus bicornis			2	2	1		9				1								15
Gen. sp. Indet. E																1		1	2
Gen. sp. Indet. F															1		2		3

Table 5 Distribution of conodonts, Delorme Formation and Road River Formation, Avalanche Lake sections AV 5, AV 6, and AV 7.

Conodonts / Number of Specimens / Mass (kg) / Sample Locality		Av 5								AV 6			AV 7				TOTAL
Number of Specimens			0	0	22	6	9	33			38	30		0	80	0	218
Mass (kg)			1.0	0.9	1.2	0.7	1.4	1.2			0.8	0.9		1.0	1.1	1.1	
Sample Locality			69	178	190	200	209	215			250	258		268	430	524	
Pelekysgnathus arcticus	I														1		1
Panderodus unicostatus						2		3							12		17
Panderodus spp.												1			31		32
Oulodus? n. sp. I	Pa?						1										1
	Sc						3										3
	Pb				2		1	1									4
Oulodus? spp.	Pa					1		?1				1					3
	Pb										?1				?2		3
	M				1												1
	Sc				1			4			3						8
	Sb				2	1		4				1			5		13
	Sa					1					1				2		4
Ozarkodina excavata excavata	Pa							2				8			5		15
	Pb							3				2			1		6
	M											2					2
	Sc							1				7			2		10
	Sb											2			1		3
	Sa							1				1					2
Ozarkodina confluens	Pa				6			8			19	1			10		44
	Pb				3			1			4				5		13
	M				2			1				1					4
	Sc				3			2				2			?1		8
	Sb											1					1
Ozarkodina spp.	Pa				1	1	3										5
	Pb						1										1
	M														1		1
	Sa														1		1
Gen. sp. Indet. E								1			6						7
Gen. sp. Indet. F					1						2						3
Gen. sp. Indet. G											2						2

The collection is divided into three main groups, separated by stratigraphic intervals where only a few conodonts were recovered. These time intervals are represented in the stratigraphic record by thick chert and shale sequences.

The oldest fauna, collected from Member 1W, Whittaker Formation, sections AV 1 and AV 4B, extends up from the Ordovician-Silurian boundary. The fauna is typical of the lower Llandovery, very sparse, dominated by *Panderodus* and other simple cone species, but characterized by *Ozarkodina hassi* (Pollock, Rexroad & Nicoll), *Ozarkodina oldhamensis* (Rexroad), *Distomodus kentuckyensis* Branson & Branson and *Oulodus? kentuckyensis* (Branson & Branson). *Oulodus? fluegeli* Walliser dominates the younger portion of the fauna. Two new species of *Ozarkodina* were recognized.

The middle fauna, collected from Member 3W, Whittaker Formation, sections AV 1, AV 2, and AV 4, is very diverse, and typical of the upper Llandovery. *Panderodus* is the most abundant genus, *Pterospathodus, Ozarkodina, Apsidognathus, Aulacognathus, Oulodus?,* and *Distomodus staurognathoides* (Walliser) are also common. New species and subspecies of *Apsidognathus, Aulacognathus, Oulodus?, Ozarkodina, Pseudooneotodus*, and *Pterospathodus* were recognized in this fauna, as well as a new genus of Pterospathodontidae.

The upper fauna, collected from Member 2D and Member 3D, Delorme Formation and Road River Formation, sections AV 4, AV 5, AV 6, and one sample from AV 7, is composed largely of *Panderodus, Ozarkodina,* and a sparse, but diverse, *Kockelella* population. New species of *Ozarkodina, Oulodus?* and two chirognathiform(?) assemblages were recognized. The fauna is typical of Wenlock species. One sample, from AV 7 430 m, contains a Ludlow-Pridoli fauna of *Panderodus, Ozarkodina confluens* (Branson & Mehl) (epsilon morphotype of Klapper and Murphy), *Ozarkodina excavata excavata* (Branson & Mehl) and *Pelekysgnathus arcticus* Uyeno. This sample is the youngest horizon in the Avalanche Lake section from which conodonts were recovered.

The biostratigraphy of the Avalanche Lake collection is similar to previously established schemes, the zonal boundaries questionable in relation to the series boundaries, which were not accurately established for the sections. Relative thickness was measured assuming uniform sedimentation and compaction throughout the sequence, with no major disconformities.

3.2 Biostratigraphy

3.2.1 Conodont Zonation

Conodonts are valuble index fossils throughout their time range. Although conodont zones for the Silurian have been established from Europe, North America and Australia, no unifying scheme exists due to the variation in faunas and ranges from the studied regions.

Conodont zones have been established by a number of methods. The earlier zones and assemblage zones were often based on the first appearance of various index species of generally unrelated taxa. A more preferable method is based on evolutionary lineages, the zones defined by the first appearances of a sequence of phyletically related index species within one lineage. Other biostratigraphic frameworks which have been used are various faunas and datum planes. Faunas are based on groups of conodonts occurring in the same range; datum planes are designated by first appearances or extinctions of important genera or species. Datum planes are boundaries or levels, whereas zones and faunas represent intervals and have a defined base and top.

When the various zones, faunas and planes are combined, a mosaic of conodont ranges is established for the entire Silurian (Fig. 8). Many of the zone boundaries coincide, indicating similarities and widespread changes in the Silurian conodont fauna. Studies following the first proposed Silurian conodont zonation (Walliser, 1964) have confirmed or modified the existing scheme.

The recognition of multielement conodont species resulted in great taxonomic change. Discrete elements, formerly having generic and specific names, are believed to be a part of an apparatus including other elements in a multielement species. From this, many of the zone and assemblage zone names, defined from form element species, have been updated to conform to multielement nomenclature (see Cooper, 1980). In all cases in the following discussion, the original zone / assemblage zone name is given as first published, followed by the zone / assemblage zone name of multielement priority, and later only referred to by the trivial name, if not already defined so. For example, *Pterospathodus celloni* Assemblage Zone of Nicoll & Rexroad (1969): *Neospathognathodus celloni* Assemblage Zone (=*Pterospathodus celloni* Assemblage

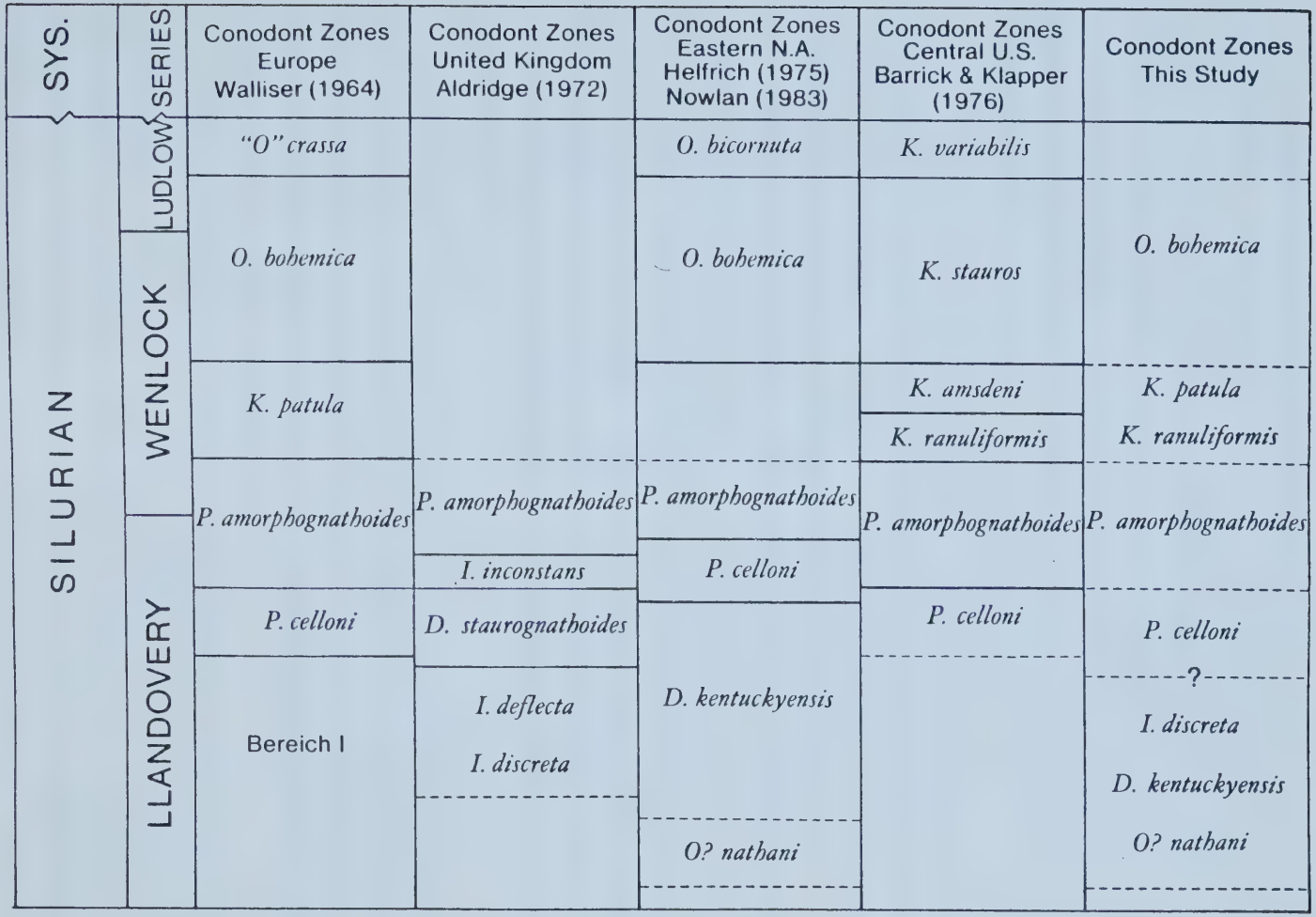

Figure 8 Lower and Middle Silurian conodont zonation of Europe and North America. The Beriech I zone of Walliser (1964) is condsidered to consist of Ordovician strata. None of the index species have yet been found to occur at the Ordovician-Silurian boundary.

Zone), the zone being referred to as the *celloni* Assemblage Zone.

Walliser (1964) established the first Silurian conodont zones. Eleven zones were named, ten being formal, ranging from the Ordovician-Silurian boundary to the base of the Devonian, though it was later shown that stratigraphic gaps occur in the section. The zones were based on conodonts mainly collected from the Cellon section of the Carnic Alps. Other samples came from sections in Europe, North America and Africa. The eleven zones were also related to existing graptolite zones, thus setting the conodont zones within an accepted time scale (Walliser, 1964, 1971).

The oldest zone was named the Bereich I. The zone is informal because of the lack of a diagnostic fauna and an undefined base. The top of the zone is defined as the base of the *celloni* Zone, the base of the Bereich I was tentatively placed at the Ordovician-Silurian boundary. The lower beds contained a conodont fauna not identifiable as, but characteristic of, Ordovician faunas. Ashgill strata are present in the Bereich I section (Gaertner *in* Walliser, 1964), though this was not asserted (Walliser, 1964). The characteristic Silurian conodont *Distomodus kentuckyensis* Branson & Branson is known only from the upper Bereich I beds. Subsequent work by Serpagli (1967) and Schönlaub (1971) established a hiatus at the base of the Silurian, indicating that the lowermost Llandovery is missing from the Cellon section, and that the lower Bereich I beds are Late Ordovician in age.

The succeeding zones overlying the Bereich I are formal conodont zones. The first occurrence of *Pterospathodus celloni* (Walliser) defines the base of the *celloni* Zone. The top of the zone is defined by the base of the *amorphognathoides* Zone. Characteristic species of this zone are *P. celloni*, *Apsidognathus tuberculatus* Walliser and *Distomodus staurognathoides* (Walliser).

The base of the *amorphognathoides* Zone is defined by the first occurrence of *Pterospathodus amorphognathoides* Walliser. The top of the zone is defined by the base of the *patula* Zone. Characteristic species of this zone are *P. amorphognathoides*, *Pterospathodus pennatus procerus* (Walliser), *A. tuberculatus*, *D. staurognathoides* and *Carniodus carnulus* Walliser.

The base of the *patula* Zone is defined by the first occurrence of *Kockelella patula* Walliser. The top of the zone is defined by the base of the *sagitta* Zone. *Kockelella patula* is the only common characteristic species in this zone at the Cellon section.

The *sagitta* Zone is defined by the first occurrence of *Ozarkodina sagitta* (Walliser), probably referring to *Ozarkodina sagitta sagitta* (Walliser) (Barrick & Klapper, 1976). The top of the zone is defined by the base of the *crassa* Zone. Species characteristic of this zone are *O. s. sagitta, Ozarkodina bohemica* (Walliser) and *Ozarkodina sagitta rhenanus* (Walliser).

The base of the *crassa* Zone is defined by the first occurrence of *"Ozarkodina" crassa* Walliser. The top of the zone is defined by the base of the *ploeckensis* Zone. Species characteristic of the zone are *"O." crassa, Kockelella variabilis* Walliser and *Ozarkodina excavata excavata* (Branson & Mehl).

The base of the *ploeckensis* Zone is defined by the first occurrence of *Ancoradella ploeckensis* Walliser. The top of the zone is defined by the base of the *siluricus* Zone. *Ancoradella ploeckensis* is rare in the Cellon section, therefore *Ozarkodina excavata hamata* (Walliser) is also an accepted index for the lower *ploeckensis* Zone. *Ozarkodina excavata excavata* and *K. variabilis* range throughout the zone, and *Ozarkodina excavata inflata* (Walliser) is restricted to the upper beds.

The base of the *siluricus* Zone is defined by the first occurrence of *Polygnathoides siluricus* Branson & Mehl. The top of the zone is defined by the base of the *latialatus* Zone. *Polygnathoides siluricus, K. variabilis* and *O. e. excavata* are characteristic of the *siluricus* Zone. *Ozarkodina confluens* (Branson & Mehl) and *Ozarkodina snajdri* (Walliser) first occur in the *siluricus* Zone at Cellon.

The base of the *latialatus* Zone is defined by the first occurrence of *Pedavis latialatus* (Walliser), and the top of the zone is defined by the base of the *crispus* Zone (=*crispa* Zone). This zone was named the *latialatus* Zone to avoid a gap in the zonal sequence, as *P. latialatus* is extremely rare. The only common species in the zone is the long ranging *O. e. excavata* (Walliser, 1964).

The base of the *crispus* Zone (=*crispa* Zone) is defined by the first occurrence of *Ozarkodina crispa* (Walliser). The top is defined by the base of the *eosteinhornensis*

Zone. *Ozarkodina crispa* and *O. e. excavata* are characteristic of this zone.

The base of the *eosteinhornensis* Zone is defined by the first occurrence of *Ozarkodina remscheidensis eosteinhornensis* (Walliser). The top of the zone is defined by the first occurrence of *Icriodus woschmidti* Ziegler. *Ozarkodina remscheidensis eosteinhornensis* is not common. Characteristic species of the zone include *O. confluens* and *O. e. excavata.*

The Silurian-Devonian boundary at Cellon is defined by the first occurrence of the graptolite *Monograptus uniformis*. *Icriodus woschmidti*, the index conodont for the base of the Devonian, is a cosmopolitan species, and first appears in the uppermost Silurian, coincident with the Silurian-Devonian boundary and the appearance of *M. uniformis* (Ziegler, 1975). *Icriodus woschmidti* has been reported from strata older than *M. uniformis*, in Upper Silurian beds from Nevada, the Cellon section, and Bohemia (Klapper and Murphy, 1975). The first occurrences of the two index species are within two meters of each other at each locality.

Conodont assemblage zones were established from the central United States to redefine the lower three zones of Walliser (1964), though the faunas generally conform to the European standard (Nicoll & Rexroad, 1969). The three assemblage zones were erected using conodonts collected from the Brassfield Limestone and Salamonie Dolomite of Indiana and Kentucky. These zones extend from above the base of the Silurian into the top of the *amorphognathoides* Assemblage Zone, which transcends the Llandovery-Wenlock boundary.

The *Icriodina irregularis* Assemblage Zone (=*Distomodus kentuckyensis* Assemblage Zone) is defined by the first occurrence of *D. kentuckyensis*. The top of the zone is defined by the base of the *celloni* Assemblage Zone. Characteristic species include *Ozarkodina oldhamensis* Rexroad and *Panderodus unicostatus* Branson & Mehl. The base of the *kentuckyensis* Assemblage Zone is above the base of the Silurian, an unconformity occurring between the Brassfield Formation and underlying Ordovician strata. Pre-*kentuckyensis* Silurian faunas have been documented from the Edgewood Dolomite, Illinois (Liebe, 1962 *in* Nicoll and Rexroad, 1969) and from the Brassfield Formation, Kentucky (Rexroad, 1967). Thus, an un-zoned gap is present from the

Ordovician-Silurian boundary to the base of the *kentuckyensis* Assemblage Zone.

The base of the *Neospathognathodus celloni* Assemblage Zone is defined by the first occurrence of the genus *Neospathognathodus* (= *Pterospathodus*) or *Ozarkodina adiutricis* (=*Pterospathodus celloni*). The top of the zone is defined by the extinction of *Pterospathodus*. With the recognition of *Neospathognathodus* as *Pterospathodus*, the resultant definition of the *celloni* Assemblage Zone would include the overlying *Pterospathodus amorphognathoides - Kockellela ranuliformis* Assemblage Zone, which was not initially intended. If the multielement species *Pterospathodus celloni* alone is used to define the assemblage zone, the integrity of the *celloni* Assemblage Zone and the *amorphognathoides - ranuliformis* Assemblage Zone remains intact. Characteristic species of the *celloni* Assemblage Zone are *D. kentuckyensis, D. staurognathoides, P. amorphognathoides, P. celloni* and *P. pennatus*.

The base of the *Pterospathodus amorphognathoides - Spathognathodus ranuliformis* Assemblage Zone (=*Pterospathodus amorphognathoides - Kockelella ranuliformis* Assembage Zone) was defined by the extinction of *Pterospathodus*, interpreted as *P. celloni*. The top of the zone is defined by the base of the *patula* Zone, though the top was not found in the Salamonie Dolomite (Nicoll & Rexroad, 1969). Characteristic species include *P. amorphognathoides, Kockelella ranuliformis* (Walliser), *Dapsilodus obliquicostatus* (Branson & Mehl) and *D. staurognathoides*. This is an abbreviated zone in comparison to the *amorphognathoides* Zone of Walliser because the range of *P. celloni* overlaps the range of *P. amorphognathoides*. Walliser (1971) stated that the redefinition of the *celloni* Zone in North America, the top of the zone defined as the extinction of *P. celloni* and not the appearance of the next zonal species, is unusual and unacceptable.

Pollock, Rexroad and Nicoll (1970), in a study of conodonts from the Michigan Basin, established a zone between the Ordovician-Silurian boundary and the base of the *kentuckyensis* Assemblage Zone of Nicoll and Rexroad (1969). The base of the *Panderodus simplex* Assemblage Zone (=*Panderodus unicostatus* Assemblage Zone) was defined by the last occurrence of conodonts characteristic of the Ordovician. The top of the zone is defined by the base of the *kentuckyensis* Assemblage Zone, or the occurrence

of *Icriodella discreta* Pollock, Rexroad & Nicoll or *Icriodella* n. sp. Pollock, Rexroad & Nicoll. The only characteristic conodonts of the zone are elements of *P. unicostatus*.

Four lower Silurian assemblage zones were proposed by Aldridge (1972) from collections in the Welsh Borderland. The four zones cover an interval similar to that studied by Nicoll and Rexroad (1969), though more closely related to the European standard erected by Walliser (1964, 1971).

The *Icriodella discreta - Icriodella deflecta* Assemblage Zone is the oldest zone. The base is defined by the occurrence of *Icriodella discreta* or *Icriodella deflecta* Aldridge, although the lower limit of the zone is unknown (Aldridge, 1972). The top of the zone is defined by the base of the *staurognathoides* Assemblage Zone. *Icriodella discreta* is characteristic of the lower part of the zone, and *I. deflecta* of the upper. Other characteristic species are *D. kentuckyensis*, though rare, and two species that occur in the upper part of the zone, *Ozarkodina hassi* (Pollock, Rexroad & Nicoll) and *O. oldhamensis*.

The base of the *Hadrognathus staurognathoides* Assemblage Zone (=*Distomodus staurognathoides* Assemblage Zone) is defined by the first occurrence of *D. staurognathoides*. The top of the zone is defined by the base of the *inconstans* Assemblage Zone. The characteristic species of this zone are *D. staurognathoides, Ozarkodina aldridgei* Uyeno, *Ozarkodina* sp. A Aldridge, *Lonchodina detorta* s. f. and *Lonchodina fluegeli* s. f. (=*Oulodus*?).

The base of the *Icriodella inconstans* Assemblage Zone is defined by the first occurrence of *Icriodella inconstans* Aldridge or *Icriodella malvernensis* Aldridge. The top of the zone is defined by the base of the *amorphognathoides* Assemblage Zone. Characteristic species are *I. inconstans, I. malvernensis, K. ranuliformis, Ozarkodina gulletensis* (Aldridge), *P. celloni* and *P. pennatus*.

The base of the *Pterospathodus amorphognathoides* Assemblage Zone was defined by the first occurrence of *P. amorphognathoides*. The top of the zone was not defined. Because of the occurrence of *P. amorphognathoides* in older strata in North America and the European continent, Aldridge (1972) redefined the base of the zone in the original work to the first occurrence of *P. amorphognathoides* in association with *K.*

ranuliformis or *Carniodus carnulus* Walliser.

Helfrich (1975) proposed six Middle through Upper Silurian zones using collections from the Appalachian Mountains along the Willis Mountain Anticline. The six zones are based on an evolutionary lineage of the genus *Ozarkodina*, thus referred to as lineage zones (Cooper, 1980). The ranges of the zonal species commonly overlap, but the first occurrence of the nominate species designates the zone.

The oldest zone, Wenlock in age, is the *Spathognathodus sagitta bohemicus* Zone (=*Ozarkodina bohemica* Zone), recognized by the occurrence of *O. bohemica, Ozarkodina aequalis, K. patula* and *Kockelella walliseri* (Helfrich). The top of the zone is defined by the base of the *bicornuta* Zone. The base of the *bohemica* Zone was originally undefined, as the lowermost member of the Mifflintown Formation was not sampled. Assignment of the lower Mifflintown Formation and the underlying Rose Hill Formation to the *patula* Zone and *amorphognathoides* Zone respectively by Helfrich (1980), confined the *bohemica* Zone to the Cosner Gap Member of the Mifflintown Formation, as was published by Helfrich (1975).

The *Spathognathodus bicornutus* Zone (=*Ozarkodina bicornuta* Zone) is defined by the first occurrence of *Ozarkodina bicornuta* (Helfrich) in association with *Ozarkodina ziegleri crassatoides* (Helfrich) and a number of form species. The top of the zone was defined by the extinction of *O. bicornuta*, resulting in an unzoned interval below the *snajdri* Zone. The top of the *bicornuta* Zone was redefined as the base of the *snajdri* Zone, eliminating the unzoned interval, by Cooper (1980).

The base of the *Spathognathodus snajdri* Zone (=*Ozarkodina snajdri* Zone) is defined by the first occurrence of *O. snajdri*. The top of the zone is defined by the base of the *tillmani* Zone. *Ozarkodina serrata* s. f. Helfrich is restricted to this zone.

The base of the *Spathognathodus tillmani* Zone (=*Ozarkodina tillmani* Zone) is defined by the first occurrence of *Ozarkodina tillmani* (Helfrich) in association with *Ozarkodina confluens multidentatus* (Helfrich). The top of the zone is defined by the base of the *crispa* Zone.

The base of the *Spathognathodus crispus* Zone (=*Ozarkodina crispa* Zone) is defined by the first occurrence of *O. crispa* and *Ozarkodina confluens highlandensis*

(Helfrich). The top of the zone is defined by the base of the *eosteinhornensis* Zone.

The base of the *Spathognathodus steinhornensis eosteinhornensis* Zone (=*Ozarkodina remscheidensis eosteinhornensis* Zone) is defined by the first occurrence of *O. r. eosteinhornensis*. The top of the zone is defined by the Silurian-Devonian boundary, signified by the first occurrence of *I. woschmidti*.

Thompson and Satterfield (1975) proposed the *Paltodus dyscritus* Fauna from Lower Silurian strata in Missouri. The *dyscritus* Fauna is recognized by *Acodus curvatus* Branson & Branson, *Acodus unicostatus* Branson & Branson, *Paltodus dyscritus* Rexroad and *P. unicostatus*, and corresponds to the *kentuckyensis* Assemblage Zone. *Acodus curvatus* and *Acodus unicostatus* have been synonymized with multielement *Walliserodus*.

Barrick and Klapper (1976) proposed a correlation scheme using a lineage of *Kockelella* from the Arbuckle Mountains of Oklahoma. The underlying *celloni* Zone and *amorphognathoides* Zone were also identified. They defined four zones, the *Kockelella ranuliformis* Zone, *Kockelella amsdeni* Zone, *Kockelella stauros* Zone and *Kockelella variabilis* Zone, which, when combined with the older *amorphognathoides* Zone, extend in age from the upper Llandovery to the lower Ludlow.

The base of the *Pterospathodus amorphognathoides* Zone was defined, as by Walliser (1964, 1971), as the first appearance of *P. amorphognathoides*. The top of the zone was defined by the base of the *ranuliformis* Zone. Other species occurring in the zone are *C. carnulus, Delotaxis petila* (Nicoll & Rexroad), *D. staurognathoides, K. ranuliformis, Ozarkodina hadra* (Nicoll & Rexroad), *Ozarkodina polinclinata* (Nicoll & Rexroad), *P. celloni, P. p. procerus*, and a diverse simple cone fauna.

The base of the *Kockelella ranuliformis* Zone is defined by the first occurrence of *Pseudooneotodus bicornis* Drygant. The top of the zone is defined by the base of the *amsdeni* Zone. *Ozarkodina excavata excavata* first appears at the base of the *ranuliformis* Zone. Species characteristic of older zones occur in the lower part of the zone, including *D. staurognathoides* and *P. amorphognathoides*. *Kockelella walliseri* first appears midway through the zone, its range extending into the overlying *amsdeni* Zone.

The base of the *Kockelella amsdeni* Zone is defined by the first occurrence of *Kockelella amsdeni* Barrick & Klapper. The top of the zone is defined by the base of the *stauros* Zone. *Ozarkodina sagitta rhenana* appears at the base of the zone. *Kockelella absidata* Barrick & Klapper, *K. patula* and *O. bohemica* first occur in the *amsdeni* Zone; *K. patula* is limited to the zone, *K. absidata* and *O. bohemica* range into younger strata.

The base of the *Kockelella stauros* Zone is defined by the first occurrence of *Kockelella stauros* Barrick & Klapper. The top of the zone is defined by the base of the *variabilis* Zone. *Kockelella absidata, O. bohemica, O. e. excavata* and *P. bicornis* also occur in this zone.

The base of the *Kockelella variabilis* Zone is defined by the first occurrence of *K. variabilis.* The top is defined by the base of the *siluricus* Zone of Walliser (1964). The *variabilis* Zone contains all the characteristic species of the *stauros* Zone with the addition of *"O." crassa.*

McCracken and Barnes (1981) established a pre-*kentuckyensis* Zone from a study of Late Ordovician - Early Silurian conodonts from Anticosti Island, Québec. The base of the *Oulodus? nathani* Zone is defined by the first occurrence of *Oulodus? nathani* McCracken & Barnes. The top of the zone is defined by the base of the *D. kentuckyensis* Zone. Characteristic species of the zone are *O.? nathani* and *D.* aff. *D. kentuckyensis. Oulodus? nathani* first occurs near the Ordovician-Silurian boundary, though the boundary was not strictly defined due to a transition zone (McCracken and Barnes, 1981). The first occurrence of *Ozarkodina* , either *O. hassi* or *O. oldhamensis*, indicates the base of the Silurian.

Cooper (1980) defined eight datum planes for the Silurian. Two types were utilised, appearance and extinction datum planes. Appearance datum planes are defined by the first occurrence of the nominate species. Only species of known evolutionary lineages were used to define datum planes. Extinction datum planes, less reliable than appearance datum planes, were defined only where a significant number of taxa appear to become extinct at the same time (Cooper, 1980). Each datum plane, where possible, is defined from a reference section in a continuous stratigraphic sequence. Advantages of

datum planes are that they are independent of defined zones and new planes can be defined and added to the sequence. The eight datum planes established by Cooper (1980) range from the middle Llandovery to the upper Ludlow, often using an index taxon which defines a previously established zone. Characteristic faunas between each datum plane were listed in Cooper (1980).

The datum planes are, in ascending order: the *Distomodus staurognathoides* Datum, *Pterospathodus amorphognathoides* Datum, *Pterospathodus* Extinction Datum, *Kockelella walliseri* Datum, *Kockelella variabilis* Datum, *Ancoradella ploeckensis* Datum, *Kockelella* Extinction Datum, and *Ozarkodina crispa* Datum. Figure 8 of Cooper (1980) illustrates the relationships of the datum planes to established zones.

Other conodont zonation schemes were proposed for the Upper Silurian of Australia (Link and Druce, 1972), and for the Upper Silurian of Europe (Jeppsson, 1974). Bultynck and Pelhate (1971) identified *O. r. eosteinhornensis* from lower in the stratigraphic record than Walliser (1964) in Bohemia, which resulted in the inclusion of the *crispa* Zone and *latialatus* Zone in the base of the *eosteinhornensis* Zone in some revised schemes. These zonal sequences do not correspond to strata or faunas of this study and are not discussed in further detail.

3.2.2 Discussion

The conodont zones proposed by Walliser (1964, 1971), although the model for succeeding Silurian conodont zones, can not be used as originally defined. The Ordovician-Silurian boundary is in the middle of the Bereich I (sample No. 5 of Walliser, 1964), not the base (Schönlaub, 1971, 1980). *Distomodus kentuckyensis* is the first Silurian index species at Cellon, indicating that the lowermost Llandovery is missing (Serpagli, 1967; Schönlaub, 1971), although *D. kentuckyensis* is the oldest Silurian zonal species at Avalanche Lake and in the central United States. The lack of overlap in zonal species indicates that other unconformities may be present in the section. Stratigraphic gaps have been implied at the base of the *celloni* Zone, *amorphognathoides* Zone, *patula* Zone, and *latialatus* Zone (Rexroad *in* Craig, 1969; Jeppsson, 1975; Barrick and Klapper, 1976).

The original proposal of the *latialatus* Zone was dubious. *Pedavis latialatus* is rare in the Cellon section, and was used as a zonal indicator due to the lack of other diagnostic species in order to prevent a zonal "gap." The alternative was to continue the *siluricus* Zone to the base of the *crispus* Zone, though the presence of *P. latialatus* in Bohemia (Bultynck and Pelhate, 1971), California (Klapper and Murphy, 1975), and in the Canadian Arctic Islands (Uyeno, 1981), in the correct stratigraphic position, demonstrates the value of the *latialatus* Zone.

The *unicostatus* Assemblage Zone of Pollock *et. al*, (1970) has not been widely used in correlation because of the of the long range of *P. unicostatus*. It was also suggested that *P. unicostatus* was restricted to specific environmental conditions (Cooper, 1975; McCracken and Barnes, 1981).

The assemblage zones proposed by Aldridge (1972) correlate approximately to those of eastern North America. The *discreta-deflecta* Assemblage Zone correlates with the *kentuckyensis* Assemblage Zone, while the *staurognathoides* Assemblage Zone and *inconstans* Assemblage Zone correspond to the extended *celloni* Assemblage Zone. The *amorphognathoides* Assemblage Zone is approximately equivalent to the corresponding zone established by Walliser (1964).

The *amorphognathoides* Zone recognized in Oklahoma corresponds to the European and Midcontinent equivalents. The *ranuliformis* Zone is unique in that it was not defined by the nominate species, but by *Pseudooneotodus bicornis*. The problem arising from this is that *K. ranuliformis* is not defining the zone in the *Kockelella* lineage. *Pseudooneotodus bicornis* has been identified from older strata: in Britain from the *celloni* Zone (Aldridge *in* Barrick, 1983), in equivalent strata from Anticosti Island (Uyeno and Barnes, 1983), and from the *amorphognathoides* Zone in Tennessee (Barrick, 1983). As a result, Barrick (1983) redefined the base of the *ranuliformis* Zone in Oklahoma as the last occurrence of *P. amorphognathoides*. The *ranuliformis* Zone and *amsdeni* Zone, as defined in Oklahoma, correspond to the *patula* Zone of Europe, *K. patula* occurring in the *amsdeni* Zone. The *stauros* Zone corresponds to the *bohemica* Zone and *sagitta* Zone,

with *O. bohemica* common to all three zones.

The *O? nathani* Zone of McCracken and Barnes (1981) is not clear as originally published. They identify *D. kentuckyensis* as occurring within the *nathani* Zone, and also the diagnostic species of the overlying *kentuckyensis* Zone. The older species should read *D.* aff. *D. kentuckyensis* (McCracken, A., University of Saskatchewan, pers. comm., 1984).

McCracken and Barnes (1981) proposed that the first appearance of Silurian species of *Ozarkodina* indicates the base of the Silurian. The recognition of the *Ozarkodina* species in lowermost Silurian strata conformably on Ordovician strata is not unique to Anticosti Island (McCracken and Barnes, 1981; Lenz and McCracken, 1982, Nowlan, 1983). This would indicate that a lowermost Silurian conodont zone would preferably be defined by *O. hassi* and/or *O. oldhamensis* and/or another *Ozarkodina* species, or be left unzoned, instead of *O? nathani*. *Oulodus? nathani* has not been found to occur at the base of the Silurian (Nowlan, 1983; McCracken, pers.,comm., 1984), but the widely recognized simple ozarkodinids have a long range above the Ordovician-Silurian boundary.

3.3 Avalanche Lake Zonation

The erection and redefinition of conodont zonations has led to a series of regional zonal schemes. A problem arising from this is the correlation of zones based on different index species, but often having a similar fauna. Commonly the fauna from one area will have similarities to more than one established regional zone scheme. The fauna collected from the Avalanche Lake sections consists of species also present in faunas from Great Britain, Europe, eastern and northern Canada, central and western United States, Southeast Asia, and Australia, indicating the wide distribution of Silurian conodonts and nonrestriction of the Selwyn Basin. Index species recognized at Avalanche Lake fit into zonation schemes proposed by Walliser (1964), Nicoll and Rexroad (1969), Aldridge (1972), Helfrich (1975), Barrick and Klapper (1976), and McCracken and Barnes (1981) [see Cooper (1980) and Nowlan (1983) for summaries of established zones]. Because of the mix of regional faunas in the study area, the zonal scheme proposed for the Avalanche

Lake region combines previously defined zones (Fig. 8). The ranges of stratigraphically important conodont species are illustrated in Figures 9 and 10.

3.3.1 Unzoned Interval

The lowermost Silurian interval begins at the Ordovician-Silurian boundary, located at AV 4B 111.6 m where *Ozarkodina hassi* first occurs. A definite Ordovician fauna was recovered from AV 4B 111.0 m. The boundary horizon at AV 1 is covered, placed at approximately 80.5 m. Samples from AV 1 78.5 m yielded an Ordovician fauna; outcrop above the covered interval is Silurian. The first Silurian zone index species, *D. kentuckyensis* of the *kentuckyensis* Zone (Nicoll and Rexroad, 1969), occurs at AV 1 92 m. The sequence below AV 1 92 m to the Ordovician-Silurian boundary, approximately 12 m thick, is left unzoned. Only long ranging species of *Ozarkodina*, *Dapsilodus*, and *Walliserodus* were recovered from this interval. In eastern Canada, *O? nathani*, like *D. kentuckyensis*, has not been found to extend its range to the base of the Silurian, leaving an unzoned interval after the last Ordovician species. Pollock *et al.* (1970) proposed the *unicostatus* Zone for this interval, but its use has not been widely accepted. Conodonts of the unzoned interval are figured in Plates 1-3.

3.3.2 *discreta/kentuckyensis/nathani* Zone

The base of the *discreta/kentuckyensis/nathani* Zone is defined by the first appearance of either of the three index species, *Icriodella discreta*, *Distomodus kentuckyensis*, or *Oulodus? nathani*. At Avalanche Lake an element of *D. kentuckyensis* first occurs at AV 1 92 m, but a Pa or M element was not recovered below AV 1 95.5 m, 3.5 m above AV 1 92 m. At AV 1 95 m, *Icriodella discreta* was recovered. This species defines the base of the lowest Silurian conodont zone of Great Britain. *Oulodus? nathani*, used to define the base of the lowest Silurian conodont zone in eastern North America (Nowlan, 1983), occurs in a single sample from AV 1 101 m, 9 m above the first appearance of *D. kentuckyensis*. The occurrence of *D. kentuckyensis* before *I. discreta* and *O? nathani* supersedes the use of the *discreta-deflecta* Zone or *nathani* Zone. *Distomodus kentuckyensis* is also the most abundant of the three index species in the lower Llandovery strata. Only one Pa element each, of *I. discreta* and *O? nathani*, was

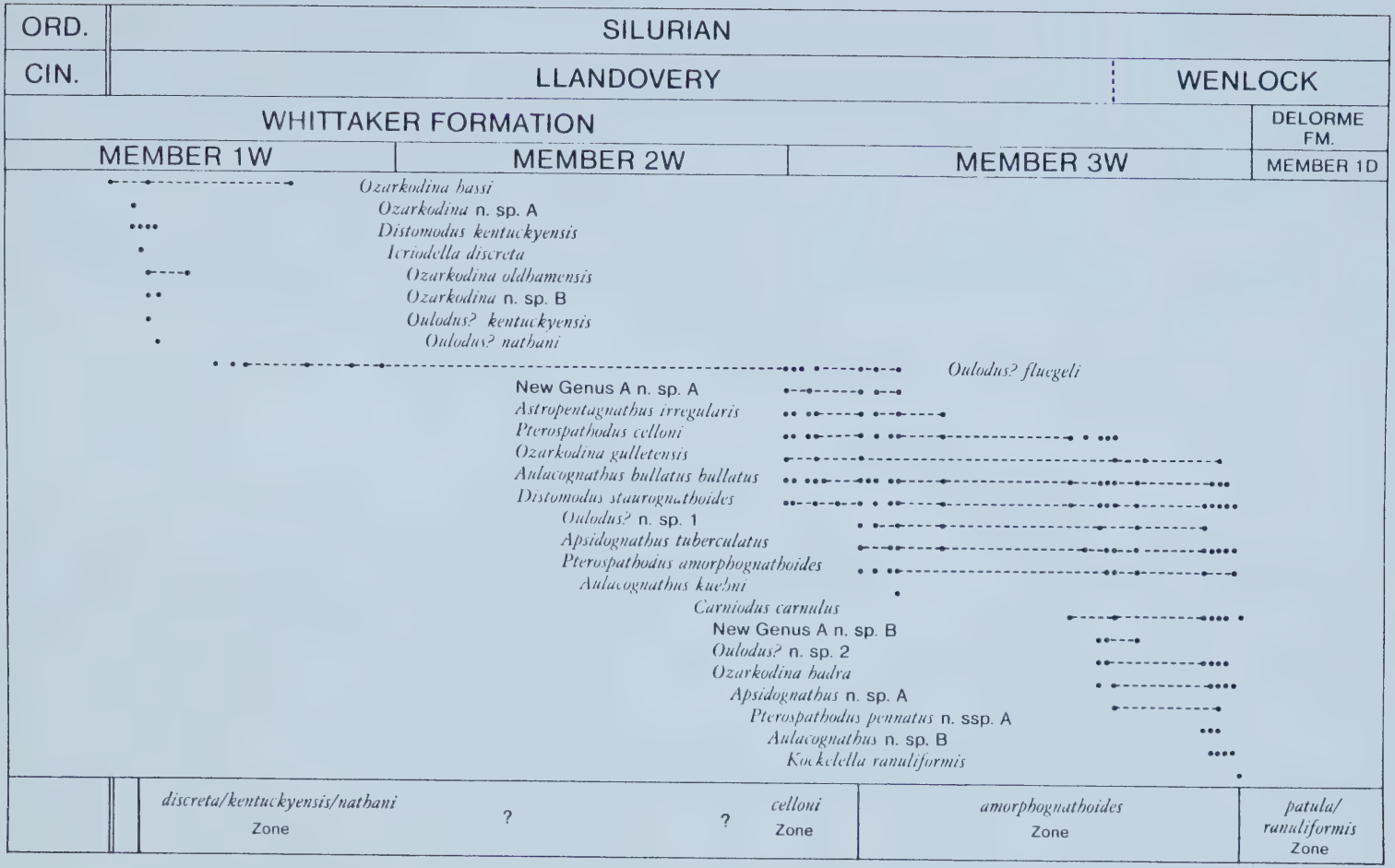

Figure 9 Ranges of stratigraphically important conodonts in the Lower Silurian at Avalanche Lake.

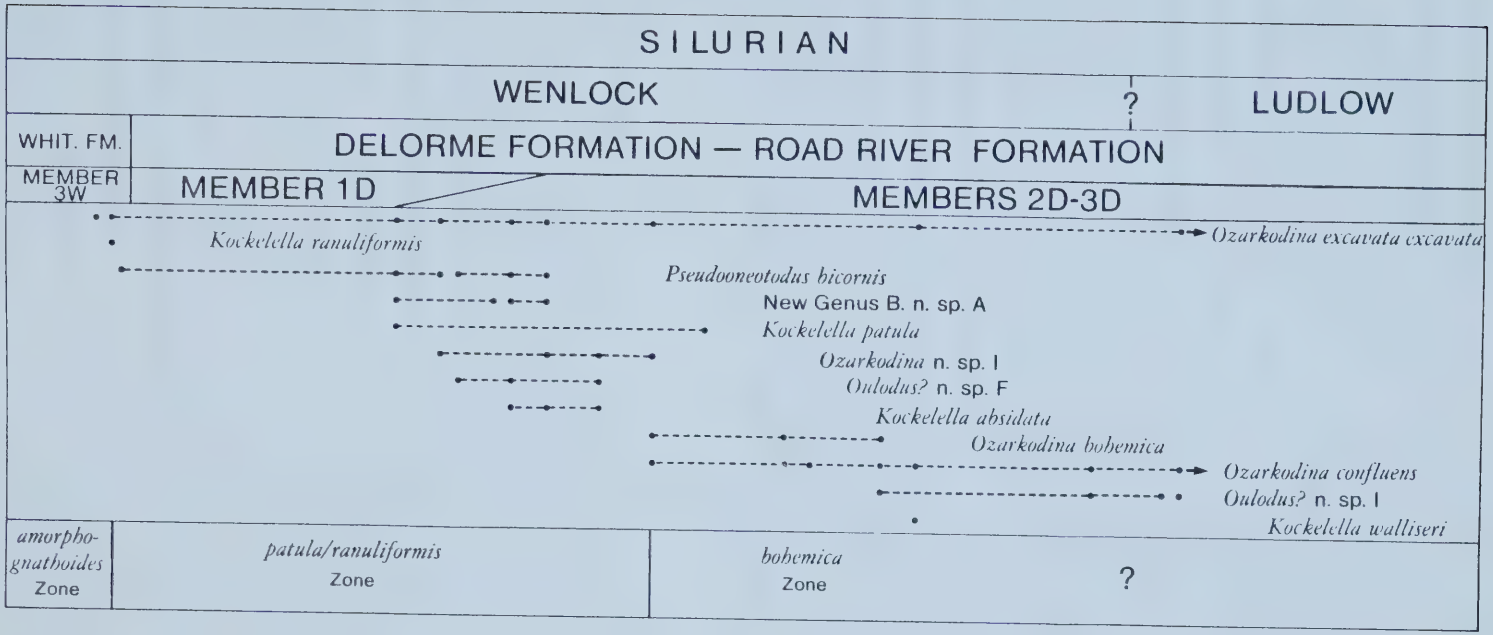

Figure 10 Ranges of stratigraphically important conodonts in the Lower-Upper Silurian at Avalanche Lake.

recovered (see Table 1). A combination of the zonal indicators is used to define the lowest Silurian zone at Avalanche Lake to indicate the mixed fauna of the region and the coincident occurrence of the species in a short interval in the Lower Silurian.

The top of the *discreta/kentuckyensis/nathani* Zone is defined by the base of the overlying *celloni* Zone. The last species characteristic of the *discreta/kentuckyensis/nathani* Zone were recovered from AV 1 101 m. *Pterospathodus celloni* first occurs at AV 1 320 m/AV 2 9 m. No index species are present for an approximately 210 m thick interval, the upper 130 m of which did not yield any conodonts. The unfossiliferous sequence is probably the result of environmental conditions, indicated by the host rock which is composed of dark, thin bedded limestone, dolostone, and chert. The lower range limit of *P. celloni* and *D. staurognathoides* probably extended into time equivalent strata of the chert. The result is a probable truncation of the overlying *celloni* Zone, and an artificial extension of the *discreta/kentuckyensis/nathani* Zone. The only ramiform element assemblage species that ranges from the *discreta/kentuckyensis/nathani* Zone into the *celloni* Zone is *Oulodus? fluegeli*. Species of the *discreta/kentuckyensis/nathani* Zone are figured in Plate 1.

3.3.3 *celloni* Zone

The base of the *celloni* Zone is defined by the first occurrence of *P. celloni*, first occurring at AV 1 320 m/AV 2 9 m. At Avalanche Lake, species first appearing coincident with *P. celloni* are *Astropentagnathus irregularis* Mostler, *Aulacognathus bullatus bullatus* (Nicoll & Rexroad), *Pterospathodus pennatus procerus* (Walliser), New Genus A n. sp. A, *Distomodus staurognathoides* (Walliser), *Oulodus?* n. sp. C, and *Ozarkodina gulletensis* (Aldridge). *Pterospathodus celloni* was used to define the zone above the *discreta/kentuckyensis/nathani* Zone instead of *D. staurognathoides*, which defines the *staurognathoides* Zone in Great Britain. This usage is consistent with the zonation schemes erected in the United States and Europe. Also, the time equivalent index species used in Great Britain, *Icriodella inconstans*, was not recognized at Avalanche Lake. A *staurognathoides* Zone can be later defined for a pre-*celloni* Zone if *D. staurognathoides* is found to precede *P. celloni* in northern Canada, as it does in eastern

Canada and Great Britain.

The top of the *celloni* Zone is defined by the base of the *amorphognathoides* Zone. All of the species occurring in the *celloni* Zone range into the overlying *amorphognathoides* Zone (see Fig. 9). Species recovered from the *celloni* Zone are figured in Plates 2 and 3. The *celloni* Zone at Avalanche Lake is possibly truncated at its base. The zonal index species first occurring above an unfossiliferous interval.

3.3.4 *amorphognathoides* Zone

The base of the *amorphognathoides* Zone is defined by the first occurrence of multielement *Pterospathodus amorphognathoides*, first appearing at AV 1 336 m / AV 2 47 m. Species first occurring coincident with *P. amorphognathoides* are *Apsidognathus tuberculatus* Walliser, *Aulacognathus bullatus* n. ssp. A, *Aulacognathus* aff. *A. latus* (Nicoll & Rexroad), *Oulodus?* n. sp. 1, and *Pseudooneotodus beckmanni* (Bischoff & Sannemann) (see Fig. 9). The fauna from the lower part of the *amorphognathoides* Zone differs from that found in the upper part of the zone. The lower part of the zone is characterized by *Astropentagnathus irregularis* Mostler, *Aulacognathus kuehni* Mostler, New Genus A n. sp. A, *Oulodus? fluegeli*, and *Pterospathodus celloni*, which do not extend to the end of the zone. Species only present in the upper part of the zone are *Apsidognathus* n. sp. A, *Aulacognathus* n. sp. B, *Carniodus carnulus*, *Oulodus?* n. sp. 2, *Ozarkodina hadra*, *Pseudooneotodus* n. sp. A, and *Pterospathodus pennatus* n. ssp. A.

The top of the *amorphognathoides* Zone is defined by the base of the *patula/ranuliformis* Zone. *Kockelella ranuliformis* (Walliser) first occurs at AV 1 460 m / AV 4 12 m (the AV 1 460 m specimen was not included in Table 2). The extinction of *P. amorphognathoides* is near this horizon. The extinction plane of *P. amorphognathoides* defines the base of the *ranuliformis* Zone in Oklahoma (Barrick, 1983), and defines the top of the *amorphognathoides* Zone in Britain where *K. patula* has not been recognized (Aldridge and Mabillard, 1981). The range of *K. ranuliformis* varies regionally. In Britain *K. ranuliformis* has been recorded from the *celloni* Zone equivalent strata. It has also been recorded from the upper *amorphognathoides-ranuliformis* Zone of Nicoll and Rexroad (1969) in the Brassfield Limestone of Indiana and Kentucky. In Oklahoma, as at Avalanche Lake, *K. ranuliformis* first occurs coincident with the last

occurrence of *P. amorphognathoides* (Barrick and Klapper, 1976). If *K. ranuliformis* is later found in older strata in the Avalanche Lake area, the top of the *amorphognathoides* Zone / base of the *patula / ranuliformis* Zone should be redefined as the extinction plane of *P. amorphognathoides*. The *P. amorphognathoides* extinction is near the top of the Whittaker Formation / base of the Delorme Formation. The exact horizon is probably between AV 1 460 m-480 m / AV 4 12 m-14.5 m, but the disappearance of *P. amorphognathoides* here may be due to a change in environment. *Ozarkodina excavata excavata* is the only non-cone species to range from the *amorphognathoides* Zone into the *patula / ranuliformis* Zone. Species characteristic of the *amorphognathoides* Zone are figured in Plates 2-5. The *amorphognathoides* Zone in the Avalanche Lake region is correlative to other established *amorphognathoides* zones.

3.3.5 *patula / ranuliformis* Zone

The base of the *patula / ranuliformis* Zone is defined by the first occurrence of *Kockelella ranuliformis* (Walliser) or *Kockelella patula* Walliser. At Avalanche Lake, *K. ranuliformis* first occurs at AV 1 460 m / AV 4 12 m; *K. patula* first occurs at AV 2 242 m. Species characteristic of the *patula / ranuliformis* Zone are *Kockelella absidata, K. patula, Oulodus?* n. sp. F, *Ozarkodina* n. sp. I, and *Pseudooneotodus bicornis* Drygant. *Kockelella ranuliformis* was only recovered from the lowermost part of the zone, the upper portion of its range is apparently truncated in this area by a shale interval that yielded no conodonts. The zone combines two index species which define zones that directly overlie the *amorphognathoides* Zone in other schemes (Fig. 8). A stratigraphic interval approximately 80 m thick occurs just above the base of the *patula / ranuliformis* Zone, from which no conodonts were recovered.

The top of the *patula / ranuliformis* Zone is defined by the base of the *bohemica* Zone. *Kockelella patula* and *O. e. excavata* continue into the overlying *bohemica* Zone. Species found in the *patula / ranuliformis* Zone are figured in Plates 6 and 7.

3.3.6 *bohemica* Zone

The base of the *bohemica* Zone is defined by the first appearance of *Ozarkodina bohemica* (Walliser). *Ozarkodina confluens* (Branson & Mehl) first appears coincident with *O. bohemica* at Avalanche Lake. Other species characteristic of the *bohemica* Zone are *Oulodus?* n. sp. I and Genus and species Indeterminate E. A poor specimen assigned to *Kockelella walliseri* (Helfrich) was also recovered.

The top of the *bohemica* Zone at Avalanche Lake is undefined. The absence of index species of the overlying zone [*Kockelella variabilis* Walliser, *Ozarkodina bicornuta* (Helfrich), or *"Ozarkodina" crassa* Walliser] make it questionable if sections AV 4, AV 5, and AV 6 extend into the Ludlow before grading into coarse dolostone. The *bohemica* Zone, of the schemes erected by Walliser (1964) and Helfrich (1975), extends into the Ludlow (Fig. 8). *Ozarkodina confluens* and *O. e. excavata* extend their range above the *bohemica* Zone, occurring in a Ludlow-Pridoli sample collected from AV 7. Species found in the *bohemica* Zone and younger are figured in Plate 7.

3.4 Lineages

Several lineages, or possible lineages, represented by sequences of related species in the Avalanche Lake collection, are potentially valuable in correlation. The lineages discussed here all include new species described in the systematics section.

The *Oulodus? fluegeli* group consists of three species of *Oulodus?* characterized by lonchodiniform or diadelognathiform Pa elements, modified ozarkodiniform Pb elements, neoprioniodiniform M elements, and a symmetry transition series of ligonodiniform, modified trichonodelliform and trichonodelliform S elements. The oldest species, *Oulodus? fluegeli* (Walliser), occurs in the *discreta/kentuckyensis/nathani* Zone, *celloni* Zone and lower *amorphognathoides* Zone. The lineage then evolves to *Oulodus?* n. sp. 1 and *Oulodus?* n. sp. 2 within the *amorphognathoides* Zone (Fig. 11). While *O?* n. sp. 1 has a diadelognathiform Pa element compared to the lonchodiniform Pa element of *O?* fluegeli and *O?* n. sp. 2, the other elements are similar in form. The elements are basically similar in morphology, but the number of denticles on the elements increases from *O? fluegeli* to *O?* n. sp. 1 to *O?* n. sp. 2. *Oulodus?* n. sp. 1 only occurs

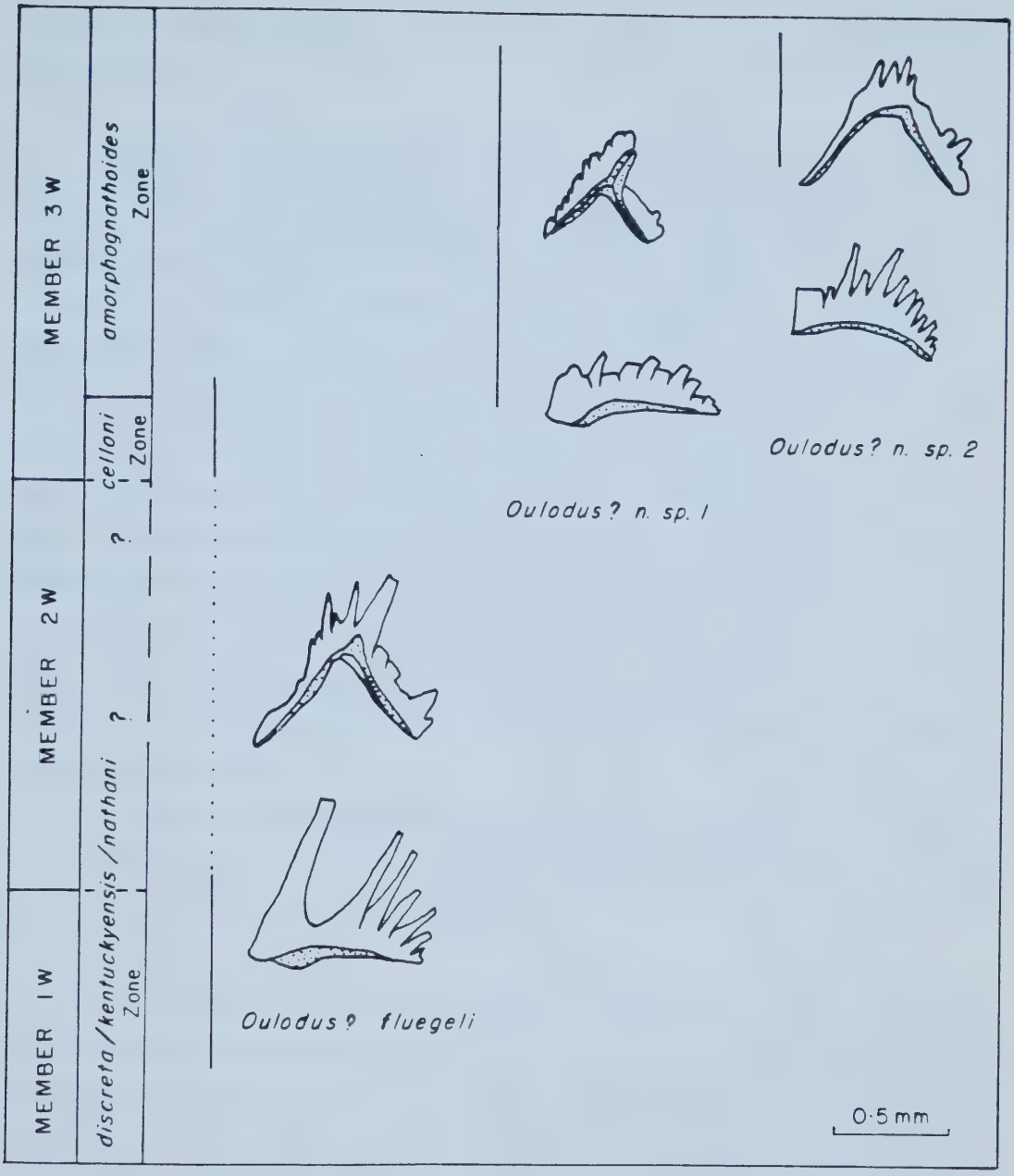

Figure 11 Stratigraphic range and morphologic comparison of the *Oulodus? fluegeli* group. The number of denticles on the elements increases in the younger species (Pa and M elements illustrated here). The vertical lines show the stratigraphic distribution.

in the *amorphognathoides* Zone, *O?* n. sp. 2 is only found in the upper *amorphognathoides* Zone (Fig. 11).

A lineage possibly developed from *Oulodus? kentuckyensis* (Branson & Branson). The *Oulodus?* species possibly descended from *O? kentuckyensis*, *Oulodus?* n. sp. C, *Oulodus?* n. sp. D, *Oulodus?* n. sp. F and *Oulodus?* n. sp. I, range, in the order listed, from the *celloni* Zone to above the *bohemica* Zone. The new *Oulodus?* species may correspond to species described in open nomenclature in other works, but revision and clarification of the genus was beyond the scope of this project. All of the species in this lineage are characterized by a Pa element with an expanded basal cavity, oulodiform denticles on the posterior process, and laterally compressed denticles on the anterior blade. The trend through the lineage, from *O? kentuckyensis* to *O?* n. sp. I, is for the Pa element to become straighter and the basal cavity to become more expanded (Fig. 12). Evolution of the Sc element is also evident, the anterior process in the younger species becomes longer and with a greater posterior deflection. The Sc element of *O?* n. sp. F does not follow the trend. Other elements within the apparatus do not clearly indicate a relationship through time.

The lack of direct intermediate forms makes a complete lineage of these species questionable. The species ranges are still valuable for regional correlation, as none of the species have an extensive time range (Fig. 12).

A lineage of *Aulacognathus* is proposed for the species recognized at Avalanche Lake. The lineage is derived only from the Pa elements (neospathognathodiform), the Pb elements are indistinguishable within the species variation, other elements of the apparatus are poorly defined, if at all. *Aulacognathus bullatus bullatus* (Nicoll & Rexroad) is the oldest and most primitive species from which the majority of the aulacognathids evolved (Fig. 13). The origin of *Aulacognathus kuehni* Mostler is not clear for this lineage, possibly developing independently of the *A. b. bullatus* lineage from *Astropentagnathus irregularis* Mostler, as proposed by Mostler (1967).

Aulacognathus bullatus bullatus first occurs at the base of the *celloni* Zone, its lower range probably truncated. *Aulacognathus bullatus* n. ssp. A and *Aulacognathus*

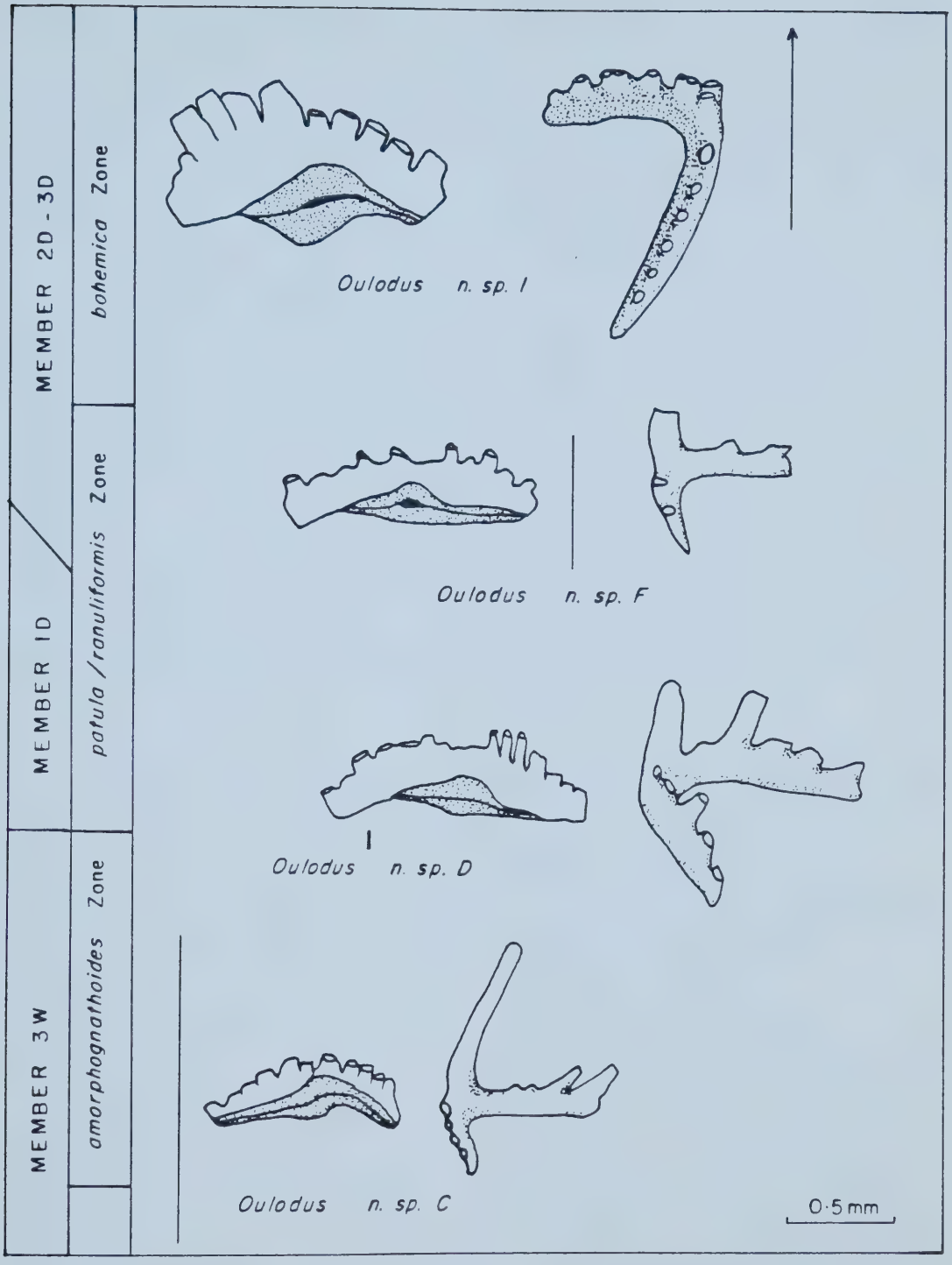

Figure 12 Stratigraphic range and morphologic comparison of *Oulodus?* n. sp. C, *Oulodus?* n. sp. D, *Oulodus?* n. sp. F, and *Oulodus?* n. sp. I. The vertical lines show the stratigraphic distribution.

aff. *A. latus* first appear in the lower *amorphognathoides* Zone. *Aulacognathus bullatus* n. ssp. A differs from *A. b. bullatus* by a greater expansion of the lateral processes, covered on the oral surface with large irregular ridges, as is *A. b. bullatus*. *Aulacognathus* aff. *A. latus* has a platform expansion similar to *A. b.* n. ssp. A, but in stead of irregular ridges, *A.* aff. *A. latus* has discrete denticles on the platforms. *Aulacognathus* aff. *A. latus* could have developed from *A. b.* n. ssp. A (Fig. 13).

Aulacognathus n. sp. A and *Aulacognathus* n. sp. B probably evolved from the *A. b. bullatus* lineage, *A.* n. sp. A from *A.* aff. *A. latus*. The origin of *A.* n. sp. B is less certain, but probably from *A.* aff. *A. latus* (Fig. 13). *Aulacognathus* n. sp. A is characterized by wide, flattened, lateral processes, an expansion of the *A.* aff. *A. latus* form with a reduction in the denticles. As discussed in the systematics, *A.* n. sp. A may be a form of *Aulacognathus latus* as originally described by Nicoll and Rexroad (1969), although it appears to be a separate species. *Aulacognathus* n. sp. B possibly evolved from *A.* aff. *A. latus*, intermediate forms have similarities to both species. The denticulation of *A.* n. sp. B is similar to that of *A. kuehni*. The ranges of these *Aulacognathus* species suggests that they could be used to subdivide the *amorphognathoides* Zone.

A lineage of *Ozarkodina* species, previously proposed for *Ozarkodina gulletensis* (Aldridge), *Ozarkodina hadra* (Nicoll & Rexroad), and *Ozarkodina confluens* (Branson & Mehl) by Barrick and Klapper (1976), does not to appear to be as simple when the Avalanche Lake fauna is considered (Fig. 14). *Ozarkodina gulletensis* first occurs in the *celloni* Zone; *O. hadra* appears in the upper *amorphognathoides* Zone, possibly developing from *O. gulletensis*. Both species extend to the top of the *amorphognathoides* Zone. The barren shale sequence of Member 1D, Delorme Formation, interrupts the distribution data available from the study area. *Ozarkodina* n. sp. I appears in the middle of the *patula/ranuliformis* Zone. *Ozarkodina* n. sp. I has Pa and Pb elements similar to those of both the older species (*O. gulletensis* and *O. hadra*) and *O. confluens*. The M and S elements were not recognized. *Ozarkodina confluens* first appears at the base of the *bohemica* Zone. The determination of the actual lineage is difficult because of the lack of intermediate forms. A lineage of any two species is possible, the other two species being branch forms. An *O. gulletensis* - *O. hadra* - *O.* n.

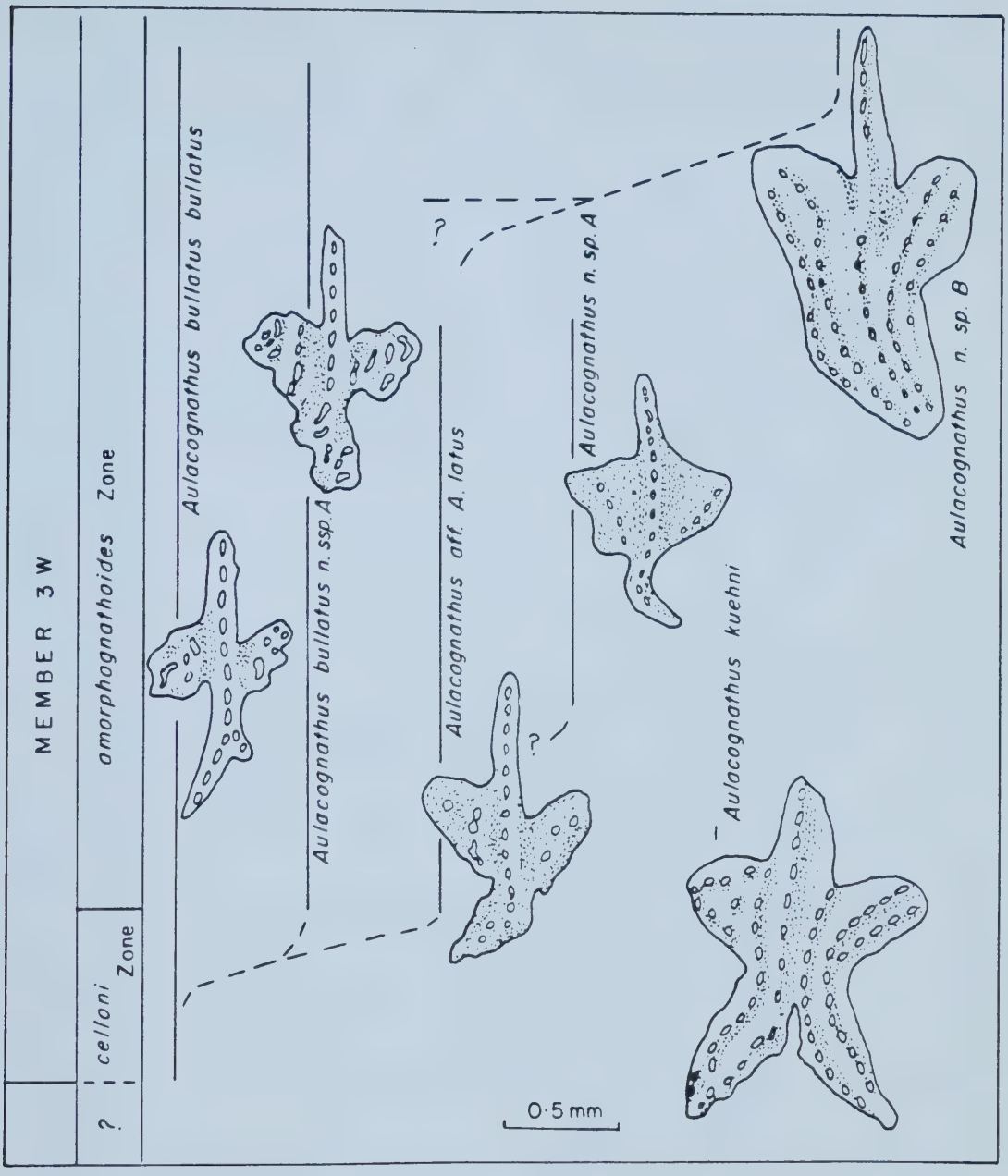

Figure 13 Species of *Aulacognathus* and their phylogenetic relationships. *Aulacognathus bullatus bullatus* is the oldest and has the least complex Pa element. *Aulacognathus* n. sp. B probably developed from *Aulacognathus bullatus* n. ssp. A or *Aulacognathus* aff. *A. latus*. The lineage of *Aulacognathus kuehni* is uncertain. The solid lines show the stratigraphic distribution.

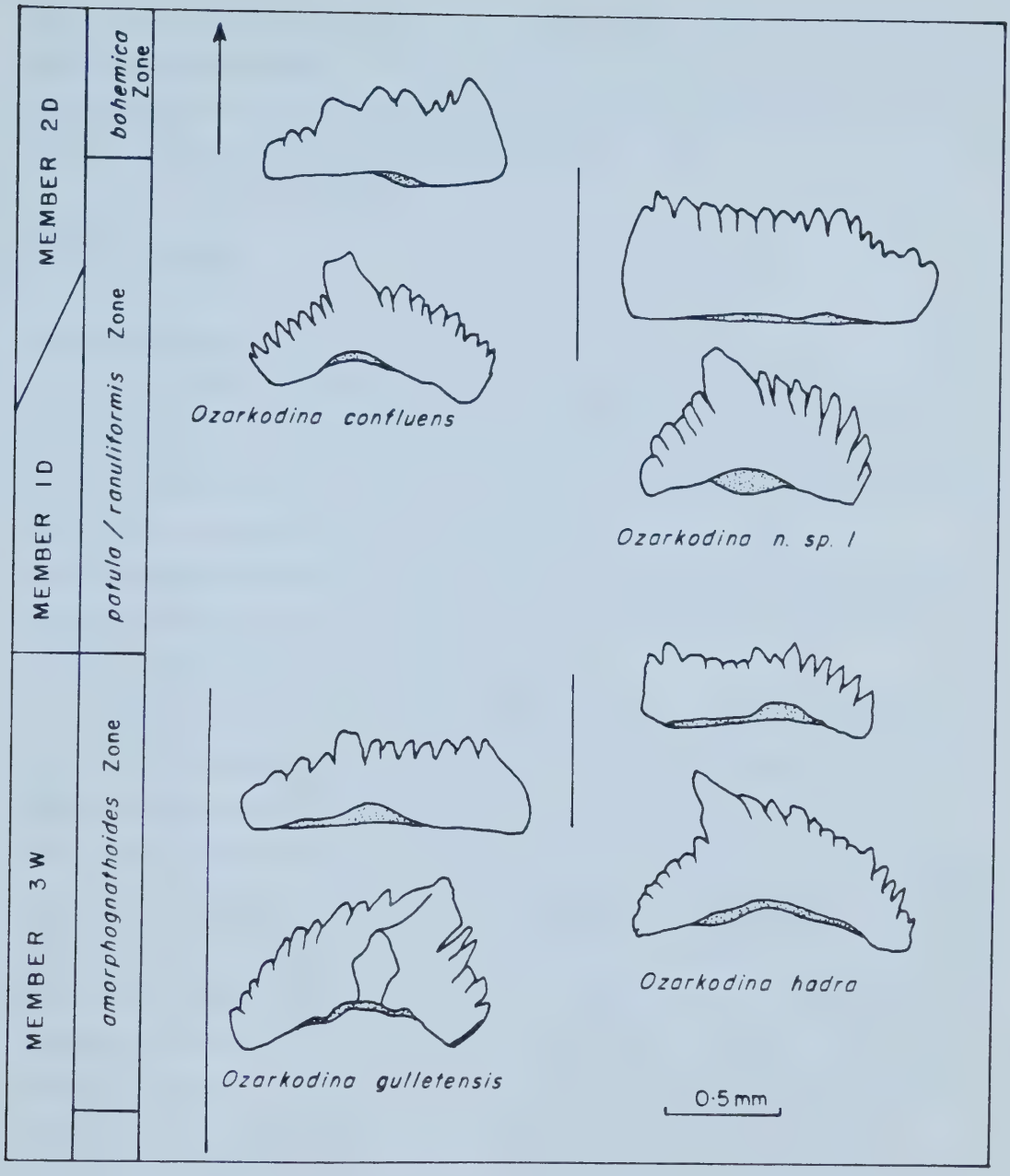

Figure 14 Stratigraphic distribution of *Ozarkodina gulletensis*, *Ozarkodina hadra*, *Ozarkodina* n. sp. 1, and *Ozarkodina confluens*. The exact lineage is questionable. *Ozarkodina confluens* may have developed through convergent evolution.

sp. I - *O. confluens* lineage is possible, but the similarity of *O. hadra* to *O. confluens* suggests a direct relationship. Another possibility, which accounts for the great variation found within *O confluens*, is that convergent evolution, from separate species, evolved into the variable forms recognized as *O. confluens*.

3.5 Paleoecology

3.5.1 Introduction

The paleoecological interpretation of conodontophorids is hampered by the lack of knowledge of the conodont animal, which has no *known* direct modern analogue. The conodont animal was probably bilaterally symmetrical. The specimen described by Briggs, *et al.* (1983) is currently the most probable representation of a complete conodontophorid. The animal is vermiform and finned, indicating an existence on or above the substrate. It has been speculated that conodontophorids were active swimmers, being predators or selective filterers.

The life mode and habitat of the conodontophorids is the crux of the problem. Life modes have been hypothesised and discussed, based on the distribution of conodont elements relative to one another and inferred environments of deposition of the host rock. Seddon and Sweet (1971) proposed a planktonic existence for conodontophorids, with a depth segregation of species producing the depositional segregation. The element distribution pattern was compared to the distribution of modern chaetognaths, which may be an ecological analogue. Barnes and Fåhraeus (1975) proposed a nektobenthic-benthic existence for most conodontophorids, indicating that only a few species were actually planktonic. Klapper and Barrick (1978) concluded that the distribution patterns used to support one life mode or the other could be produced by planktonic, nektonic or nektobenthic organisms, and cited examples of distribution patterns of modern organisms. With no encompassing life mode model presently accepted, it should be considered that a combination of the models is probable. The conodontophorids were variable and widespread, probably filling planktonic, neritic, and nektobenthic niches, as indicated by their elements and distribution. Environmental factors such as salinity, temperature, O_2 concentration, substrate, oceanic currents, and food supply, were the

main parameters controlling conodont distribution. A short review of these factors is given by Clark (1981). Aldridge and Mabillard (1981), in a study of an *amorphognathoides* Fauna from the Welsh Borderland, concluded that the conodont distribution was the result of environmental preferences.

With no definite life mode universally accepted for most of the species, and the paleoenvironmental conditions difficult to interpret accurately, paleoecological interpretations have been based on the faunal and host rock associations, and paleogeographical reconstructions. For the Silurian, paleoecological studies are limited to a small number of studies from North America and Britain. The life mode is usually interpreted in reference to water depth, distance from shore, and energy, although some species are associated with hypersaline conditions. The uses of the terms 'offshore', 'shallow-water', 'deep-water', and 'high energy' are all relative. In reference to the Avalanche Lake sections, the term 'deep-water' implies water depths in excess of those colonized by the reef forming community, typical of Benthic Association 4-6 and the Pelagic Community (Boucot, 1975).

Interpretations previously presented for given species vary regionally, indicating either wide environmental tolerances, or regional distribution controlled by differing environmental conditions. The conodonts from Avalanche Lake, recovered from deposits interpreted as quiet water subtidal, include species which have been recovered from littoral to deep-water offshore deposits by other researchers. Commonly, species recorded from widely differing environments will occur in the same sample. Table 6 lists Avalanche Lake species that have been attributed to certain environments by other authors.

3.5.2 Paleoecology-Avalanche Lake

The conodont fauna at Avalanche Lake is generally indicative of a deep-water setting. *Panderodus, Dapsilodus, Decoriconus,* and *Walliserodus* are considered to have been pelagic. *Oulodus?* was possibly a nektonic or nektobenthic genus. The genera which have platform elements, such as *Distomodus, Aulacognathus, Ozarkodina,* and *Pterospathodus,* were probably nektobenthic.

Table 6 Partial list of paleoenvironmental interpretations of Silurian conodontophorids, based on element association and host rock interpretation. Ll = Llandovery; W = Wenlock; L = Ludlow; l = lower; m = middle; u = upper. A = Aldridge (1976), Britain; A&M = Aldridge and Mabillard (1981), Welsh Borderland; B = Barrick (1983), Tennessee; LF = LeFèvre, *et al*. (1976), Hudson Bay Basin; N = Nowlan (1983), eastern Canada; U&B = Uyeno and Barnes (1983), Anticosti Island.

Species	Age	Interpretation	Locality Author(s)
Dapsilodus	Ll	offshore	A&M
	Ll-L	offshore / pelagic	B
	Ll	shallow water	U&B
Decoriconus	Ll	deep-water	N
Panderodus	Ll	near-shore / pelagic	N
	Ll	pelagic	LF
	Ll-W	shallow / high energy	B
	Ll-L	deep-water	A
	Ll	high energy	U&B
Walliserodus	Ll	deep-water	N
	Ll-W	deep-water	A
Apsidognathus	Ll	deep-water	LF
	Ll	deep-water	N
	Ll	high energy	U&B
Aulacognathus	Ll	subtidal	LF
D. kentuckyensis	Ll	littoral	LF
	Ll	deep-water	N
D. staurognathoides	Ll	high energy	
		shallow / deep	A
	Ll	deep-water	N
	Ll	wide distribution	A&M
	Ll	high energy	U&B

Table 6 cont.

Species	Age	Interpretation	Locality Author(s)
C. carnulus	LI-W	deep-water	A
	LI-W	deep-water	N
	LI-W	deep-water	B
	LI	high energy	U&B
Icriodella	LI	littoral	LF
	LI	shallow	N
Oulodus?	LI	wide distribution	A
	mLI	offshore	A&M
	LI	shallow	N
O. bohemica	W	deep shelf	A
O. confluens	W	deep shelf	A
	L	wide distribution	A
O. e. excavata	LI	wide distribution	A
	mLI	wide distribution	A&M
	lLI	nearshore	A&M
	W	offshore	A&M
	W	deep shelf	A
	L	wide distribution	A
O. hassi	LI	shallow-water	A
	lLI	near shore	N
	mLI	offshore	N
Pterospathodus	LI	subtidal	LF
	LI	deep-water	A
	LI	not shallow	N
	LI-W	offshore	A&M
	LI-W	deep-water	B

The conodont fauna of Member 1W, Whittaker Formation, beginning at the Ordovician-Silurian boundary, can be divided into two groups. The older fauna is dominated by *Panderodus, Dapsilodus,* and simple species of *Ozarkodina*. The younger fauna is dominated by *Oulodus? fluegeli*, the range of which extends above the deep-water chert interval of Member 2W into Member 3W. The oldest Member 1W fauna contains species indicative of different environments (Table 6). *Icriodella* and *D. kentuckyensis,* both found in littoral deposits of the Hudson Bay Basin (LeFèvre, *et al.*, 1976), are found in samples with the deep-water forms *Dapsilodus, Panderodus,* and *Walliserodus*. The lowermost Llandovery was an interval of lower sea level, possibly inducing the basinward retreat of shallow-water forms. The deep-water nature of the Avalanche Lake deposits and the associated fauna indicate that the sequence was subtidal, with *Icriodella* and *D. kentuckyensis* responding to a change in salinity or temperature. *Icriodella discreta* occurs in dark, argillaceous micrite, containing gypsum pseudomorphs, indicating hypersalinity of the bottom waters. If *I. discreta* is indeed nektobenthic and euryhaline, the species could possibly live in the bottom hypersaline environment. *Icriodella discreta* could also have been transported after death.

The younger Member 1W fauna is dominated by *O? fluegeli*, and also contains *Dapsilodus, Panderodus,* and *Walliserodus*. The decline in the ozarkodinids, and other species of *Oulodus?* and *D. kentuckyensis* higher in the section toward the base of the chert unit, indicates a deepening trend. The species present are all believed to be pelagic or nektobenthic-nektonic. *Oulodus?* was possibly both nektobenthic and nektonic. The presence of a dwarf *O? fluegeli* fauna at AV 1 124 m is evidence for a nektobenthic existence. Environmental stress can cause dwarfism, but pelagic taxa are not responsive to restrictive conditions unless the entire basin is affected. The presence of normal elements in the sample (one *Oulodus?* apparatus and a number of simple cones) reflects the presence of nektonic / planktonic forms. The wide distribution of *Oulodus?* in shallow and deep-water deposits suggests a nektonic life mode.

Member 2W, consisting of deep-water chert and secondary dolostone, did not yield any conodonts from the scattered limestone horizons.

The fauna from Member 3W can be divided into three groups: lower, middle, and upper faunas. The lower fauna (*celloni* Zone and lower *amorphognathoides* Zone) is

dominated by *Panderodus, Astropentagnathus, Aulacognathus,* and *Pterospathodus*. The fauna contains species indicative of shallow-water, notably *D. staurognathoides* and *A. b. bullatus,* and deep-water forms such as *Pterospathodus* (Table 6). All the species in the lower fauna are considered to be deep-water, the simple cones pelagic, and the *Oulodus?* species nektobenthic and/or nektonic. The species with platform elements were probably nektobenthic. In eastern Canada, the absence of *P. celloni, P. amorphognathoides,* and *C. carnulus* in upper Llandovery strata is coincident with shallow-water deposits containing *Oulodus?* (Nowlan, 1983). At Avalanche Lake the forms occur in the same samples, though *C. carnulus* does not appear until the upper Member 3W fauna.

The middle Member 3W fauna is extremely sparse, dominated by *Panderodus*. The host rock indicates deeper water than that occupied by the lower fauna. The rock is more argillaceous and cherty, similar to Member 2W. The reduced fauna concentration is a function of greater water depth and a more distal position from shore. This occurrence is consistent with a nektonic and nektobenthic existence for conodontophorids with pectiniform and ramiform element apparatuses. True planktonic forms such as *Panderodus* and offshore nektonic forms of *Oulodus?* occur in the deposits.

The upper Member 3W fauna, except for the extinction of *A. irregularis* and N. Gen. A n. sp. A, and the addition of a number of species, is similar to the lower Member 3W fauna (see Fig. 9). The dominant genera are *Pterospathodus* and *Panderodus,* with *Oulodus?, Ozarkodina, Apsidognathus, Distomodus, Carniodus,* and *Decoriconus* also common. As indicated in Table 6, *P. amorphognathoides, P. celloni* and *C. carnulus* are characteristic of deep-water settings. *Panderodus* and *Decoriconus* are considered to be planktonic forms. The associated conodonts therefore fall into the same setting, being either nektobenthic or nektonic in the deep-neritic zone.

Member 1D, Delorme Formation, yielded only a few conodonts from limestone horizons (gravity flows?) in the shale sequence. Graptolites are common throughout the member, indicating deep-water.

The fauna of Member 2D and Member 3D is dominated by *Panderodus* and species of *Ozarkodina*. *Panderodus,* ubiquitous through the section, is a pelagic form, and not indicative of depth. The ozarkodinids, *O. bohemica, O. confluens,* and *O. e. excavata,* have

been reported from deep-water shale and deep-shelf limestone (Aldridge, 1976). The Avalanche Lake fauna of *Kockelella* and *Ozarkodina*, though sparser, is similar to the fauna described by Barrick and Klapper (1976) of the same age from the Fitzhugh Member, Clarita Formation, Arbuckle Mountains. The Fitzhugh Member, composed of biomicrite to biosparite, typically in moderately thin, uniform beds, was deposited in a relatively quiet water environment (Amsden, 1968). The indication is that some *Kockelella* and *Ozarkodina* species populated the deep-shelf, and were probably nektobenthic. The depositional environment of Member 2D and Member 3D is also interpreted as deep-shelf.

The occurrence in Member 2D of chirognathid like conodonts (N. Gen. B n. sp. A), indicative of shallow, possibly supersaline conditions, is attributed to basinward transport of either the conodontophorids or of material containing the conodont elements. This form of conodont has generally been reported from shallow-water. The abundance of N. Gen. B n. sp. A in one sample, which also yielded *Ozarkodina* and *Panderodus*, is attributed to transport of the shallow-water forms off shore by gravity flow, and a mixing of the fauna with deeper water species such as *O. e. excavata* and *O.* n. sp. I.

A sample collected from AV 7 430 m yielded a mixed conodont fauna dominated by *Panderodus*, *Ozarkodina confluens*, and *Ozarkodina excavata excavata*. A single element of *Pelekysgnathus arcticus* was also identified. This sample was from a locality 7 km southeast of AV 6, in argillaceous limestone of presumably deeper water origin. This fauna is similar to a shelf fauna described by Uyeno (1981) from the Upper Silurian of the Boothia Uplift. From these two occurrences a wide distributional range and tolerance is indicated for *Pelekysgnathus* and *Ozarkodina*.

3.5.3 Discussion

The life mode of the conodontophorids varied. Their distribution can be explained by postulating either nektonic or nektobenthic life modes for most genera, with some species being planktonic and hence unaffected by depth. Conodontophorids with simple cone apparatuses, such as *Dapsilodus*, *Decoriconus*, *Panderodus* and *Walliserodus*, were planktonic or pelagic forms. These taxa are widespread and long ranging, occurring in deposits from from near shore to off shelf, although *Panderodus* is the most common

form in shallow-water sediments. Species of *Oulodus?* probably filled nektobenthic and nektonic niches in the neritic zone. *Pterospathodus* and *Carniodus* are limited in the record to reports from deep-shelf deposits, suggesting an off shore nektonic or deep-water nektobenthic life mode. *Ozarkodina, Distomodus,* and *Apsidognathus* occur in similar environments to *Pterospathodus*, as well as shallower subtidal settings. All of the species from Avalanche Lake are considered to be preserved in subtidal deposits, typically deposited in a deep-shelf to transitional-slope setting. The occurrence of exotic species in the deep-water deposits, and the presence of faunas with conodonts derived from different water depths, are attributed to depth zonation of certain conodont species and transport of near shore material to distal locations by gravity flows.

3.6 Paleogeography

North American and European faunal provincialism of conodonts is well established during the Ordovician. Two main faunal groups are recognized: the Midcontinent Fauna, and the North Atlantic Fauna (Bergström, 1971). In the Silurian, provincialism is much less definite, a reflection of both the smaller number of studies and the more widespread distributions of most conodont genera. Lower Llandovery faunas are regionally different (Barnes, *et al.*, 1973), possibly reflecting a continuation of Upper Ordovician provincialism. Different faunas in the upper Llandovery have been recognized from two areas. In the Michigan Basin, the northern fauna differs in composition from the southern fauna (Pollock, *et al.*, 1970), possibly as the result of barrier complexes which divide the basin. A similar faunal division was recognized by Aldridge (1970 *in* Barnes, *et al.*, 1973) from the Llandovery area of Britain.

Most conodonts of late Llandovery, Wenlock, and Ludlow age have a wide distribution, but a number of species have a more regional distribution. The presence of a number of species known only from geographically restricted regions at Avalanche Lake, indicates that the Selwyn Basin was an area of faunal mixing, and suggests that the basin was not restricted in regards to conodont movements from other regions (in particular Europe and central and western United States).

The conodont species recognized at Avalanche Lake that show a regional distribution are listed in Table 7. The absence of some species such as *Apsidognathus*

Table 7 Conodonts recognized at Avalanche Lake that have a regional distribution in North America and Europe. For references of the taxa listed, see the appropriate synonymy and Remarks in the Systematics.

w. US	c. US	AV Lake	e. NA	Britain	w. Eur.	n. Eur.	
X		X	X	X	X		*Apsidognathus tuberculatus*
X		X	X	X	X		*Astropentagnathus irregularis*
X	X	?	?				*Aulacognathus latus*
	X	X		X		X	*Icriodella discreta*
	X	X			X		*Kockelella patula*
	X	X	X				*Kockelella walliseri*
		X	X	X			*Ozarkodina gulletensis*
X	X	X					*Ozarkodina hadra*
	X	X	X	X		X	*Ozarkodina hassi*
	X	X	X	X		X	*Ozarkodina oldhamensis*

tuberculatus, *Astropentagnathus irregularis*, and *O. gulletensis* from localities in the central and western United States may reflect temperature or depth preferences of these taxa, which appear to be absent from the Silurian North American epeiric sea. *Apsidognathus* sp. s.f. was recorded from California (Miller, 1978), while *A. irregularis* was recorded from Nevada (Klapper and Murphy, 1975). Both localities were close to the continental edge in Silurian time. The presence of these "European" species at Avalanche Lake and down the western margin of North America, indicates a faunal link of this area to Europe and / or Asia.

Aulacognathus latus / *Aulacognathus* aff. *A. latus* is found in North America. *Icriodella discreta*, *Ozarkodina hassi*, and *Ozarkodina oldhamensis* have only been recovered from the central United States, eastern Canada, Britain, Norway, and Siberia (Männik, 1983). This distribution would require a faunal link from Avalanche Lake across Arctic Canada to Québec and Europe / Asia, and a connection across the North American epeiric sea to the United States. These species have been recorded from shallow-water strata, indicating potential exchange across the epeiric sea. The aulacognathids may have preferred deeper water, as they occur in areas closer to the Silurian continental margins.

Ozarkodina hadra has only been recognized in North America: from the upper *amorphognathoides* Zone at Avalanche Lake; from the same zone in Oklahoma (Barrick and Klapper, 1976); with an *amorphognathoides* fauna in Indiana and Kentucky (Nicoll and Rexroad, 1969); and in Nevada (Klapper and Murphy, 1975). The species possibly fills the same niche as *O. gulletensis*, or is a regional evolutionary form. *Ozarkodina hadra* and *O. gulletensis* are both believed to be related to *O. confluens*. *Ozarkodina hadra* possibly branched from a *O. gulletensis* - *O. confluens* line, and become established in North America.

Kockelella patula and *Kockelella walliseri* do not reflect any of the Llandovery distributions, indicating different distribution factors prevailed in the Wenlock. The different distribution of the two species may represent either environmental preference or regional evolution. *Kockelella walliseri* appears to be a direct branch from *K. ranuliformis*, but *K. walliseri* does not have as wide a distribution as the older species.

Distomodus staurognathoides has a wide distribution, occurring throughout North America, Britain, and Europe. The *"Johnognathus"* form element, assigned to *D. staurognathoides* (see discussion in Systematics), does not have the same wide distribution. *"Johnognathus"* elements have been reported from the western Ukrainian S. S. R. (Mashkova, 1977), Britain and Scandinavia (Aldridge and Mohamed, 1981; Mabillard and Aldridge, 1983), and eastern Canada (Uyeno and Barnes, 1983). Unlike other distribution differences, the geographic distribution of this element of *D. staurognathoides* is not as wide as that of the species. This element possibly represents a regional race or subspecies of *D. staurognathoides*. The *"Johnognathus"* form first appears in the *amorphognathoides* Zone. The geographic distribution of this element indicates a connection between the Selwyn Basin, across Arctic Canada to eastern Canada, Britain, Scandinavia, and the Ukraine.

The distinct difference in the geographic distribution of relatively wide spread species in the Lower Silurian, in combination with ubiquitous species, is a reflection of environmental preference or regional evolution of certain species. Other factors controlling distribution are species migrations and the effects of physical barriers and currents in the Silurian seas. The composition of the Avalanche Lake fauna suggests that interchange of shallow-water species could have occurred between the Selwyn Basin and the region of the "Midcontinent" fauna in the Silurian North American epieric seas. Deep-water species were connected to other faunas by dispersal along the present day northern and western continental margins. The high proportion of cosmopolitan taxa in the Avalanche Lake fauna indicates that regular interchange took place with other areas, and therefore indicates that the Selwyn Basin was not restricted during the Early Silurian.

While these observations have been qualitative, a more rigorous assessment could be made using similarity indices such as the Provinciality Index of Johnson (1971), or other statistical techniques, to obtain more quantitative distribution relationships. In dividing the conodont sequence into established time intervals, corresponding with species ranges, a sequence of regional and cosmopolitan faunas and their transition patterns through time could be established.

4. SYSTEMATIC PALEONTOLOGY

The terminology assigned to elements of multielement conodont apparatuses is that of Sweet and Schönlaub (1975), modified by Cooper (1975, 1976, 1977b), and that of Klapper and Philip (1971, 1972) for *Pelekysgnathus*. The morphology of the conodont elements in the multielement apparatus is often described in reference to the original form genus of that element. An example is the ligonodinifrom Sc element typical of the genus *Oulodus?*. *Ligonodina* s.f. was the form genus. The form genera can be found in most conodont works published before 1975; the majority are listed in the first edition of the Treatise on Invertebrate Paleontology, Part W (Hass, 1962). The conodont taxonomy used is as in the Treatise on Invertebrate Paleontology, Part W (Robison (ed.), 1981).

PHYLUM CONODONTA Eichenberg, 1930

CLASS CONODONTA Eichenberg, 1930

ORDER CONODONTOPHORIDA Eichenberg, 1930

SUPERFAMILY PRIONIODONTACEA Bassler, 1925

4.1 Family Icriodontidae Müller & Müller, 1957

4.1.1 Genus *Icriodella* Rhodes, 1953

Type Species

1953 *Icriodella superba* - Rhodes: p.287.

Remarks

Multielement *Icriodella* is composed of four distinct skeletal form elements (Cooper, 1975): Pa, Pb, M, and S. The Pa element is icriodiniform; Pb is ambalodiniform or sagittodontiform; M is sagittodontiform; S is variable, rhynchognathodontiform, trichonodelliform, or zygognathiform.

Only one element from the Avalanche Lake collection is definitely assigned to *Icriodella*, a Pa element described as *Icriodella discreta*. One other element is

questionably identified based on morphology and occurrence.

Icriodella discreta Pollock, Rexroad & Nicoll, 1970

Plate 1, Figures 14, 18

Pa Element

1970 *Icriodella discreta* - Pollock, Rexroad, and Nicoll: p. 754, Pl. 111, Figs. 27-30.

Pb Element

1970 *Distomodus triangularis triangularis* (Walliser) - Pollock, Rexroad, and Nicoll: p. 750-751, Pl. 112, Figs. 2-6.

M Element

1947 *Trichonodella? edentata* - Branson and Branson: p. 552, Pl. 82, Figs. 28, 40, 44, 48.

S Element

1964 *Roundya brevialata* - Walliser: p. 69, Pl. 4, Fig. 16; Pl. 31, Figs. 8-10.

Multielement

1975 *Icriodella discreta* Pollock, Rexroad & Nicoll - Cooper: p. 1004, Pl. 2, Figs. 1-4.

1982 *Icriodella discreta* Pollock, Rexroad & Nicoll - Aldridge and Mohamed: Pl. I, Figs. 11-15.

Diagnosis

The Pa element is characterized by a platform with an offset posterior blade. Denticles on the platform are paired, a single row on the blade, decreasing in size posteriorly. The basal cavity is narrow and shallow, widening and deepening at the platform-blade junction, typically forming flares or lateral processes on the blade. The other elements in the apparatus are not diagnostic.

Description

The elements assigned to *I. discreta* have been described in the literature. The form elements have been described by Pollock, *et al.* (1970). A multielement description was given by Cooper (1975).

Remarks

The Pa element found is most like the holotype of Pollock, *et al.* (1970) and the element illustrated by Cooper (1975). A Pb? element was found in the sample with the Pa.

Being of similar luster and comparable size it is included with *I. discreta*, though it does not resemble any previously described element assigned to this species. It is questionably assigned a Pb position, but may occupy a transitional position.

Range

Icriodella discreta occurs in the *discreta/kentuckyensis/nathani* Zone at Avalanche Lake.

Material studied

1 Pa, 1 Pb?.

4.1.2 Genus *Pelekysgnathus* Thomas, 1949

Type Species

1949 *Pelekysgnathus inclinatus* - Thomas: p. 424-425, Pl. 2, Fig. 10.

Remarks

Multielement *Pelekysgnathus* is composed of three distinct skeletal form elements (Klapper and Bergström, 1981): I, M, and S. The I element is icriodiniform; M are smooth or costate cones; S are smooth or costate cones with circular or elliptical cross sections.

Pelekysgnathus arcticus Uyeno, 1981

Plate 7, Figure 22

1981 *Pelekysgnathus arcticus* - Uyeno: p. 45-46, Pl. 7, Figs. 1-27.

Diagnosis

The I element consists of a denticulated blade with a large posterior denticle over a posteriorly expanded basal cavity.

Description

Elements of *P. arcticus* have been described by Uyeno (1981).

Remarks

A single specimen of *P. arcticus* was collected from the youngest Avalanche Lake sample that yielded conodonts (AV 7 430 m). Other taxa in the sample are *O. confluens* (epsilon morphotype) and *O. excavata excavata*. *Pelekysgnathus arcticus* occurs in strata of late Ludlow to middle Pridoli age in the Arctic Islands (Uyeno, 1981).

Material studied

1 l.

4.2 Family Rhipidognathidae Lindström, 1970

4.2.1 Genus *Carniodus* Walliser, 1964

Type Species

1964 *Carniodus carnulus* - Walliser: p. 32-33, Pl. 6, Fig. 10; Pl. 10, Figs. 20, 21; Pl. 27, Figs. 27-38; Pl. 28, Fig. 1; Text-Fig. 4 a-f.

Remarks

Multielement *Carniodus* is composed of six distinct skeletal form elements (Barrick and Klapper, 1976): Pa, Pb, M, Sc, Sb, and Sa. The Pa element is carnuliform; Pb is carinthiaciform; M is carniform; Sc is subcarniform; Sb is carniform; Sa is latialatiform.

Carniodus carnulus Walliser, 1964

Plate 4, Figures 25-27

Pa Element

1964 *Carniodus carnulus* - Walliser: p. 32-33, Pl. 6, Fig. 10; Pl. 10, Figs. 20, 21; Pl. 27, Figs. 27-38; Pl. 28, Fig. 1; Text-Fig. 4, a-f.

Pb Element

1964 *?Carniodus carinthiacus* - Walliser: p. 31-32, Pl. 6, Fig. 11; Pl. 27, Figs. 20-26; Text-Fig. 4 u.

M Element

1964 *Carniodus carnicus* - Walliser: p. 32, Pl. 6, Fig. 11; Pl. 28, Figs. 8-11.

Sc Element

1964 *Neoprioniodus subcarnus* - Walliser: p. 51-52, Pl. 5, Fig. 7; Pl. 28, Figs. 12-18.

Sb Element

1964 *Carniodus carnus* - Walliser: p. 34, Pl. 5, Fig. 3; Pl. 10, Fig. 13; Pl. 28, Figs. 2-7; Text-Fig. 4 y-z.

Sa Element

1964 *Roundya latialata* - Walliser: p. 71, Pl. 6, Fig. 15; Pl. 31, Figs. 11-14.

Multielement

1964 Conodonten-Apparat D - Walliser, p. 17.

1972 *Carniodus carnulus* Walliser - Walliser: p. 76-77.

1975 *Carniodus carnulus* Walliser - Aldridge: Pl. 1, Figs. 3, 4, 8, 9.

1976 *Carniodus carnulus* Walliser - Barrick and Klapper: p. 68-69, Pl. 1, Figs. 1, 2, 6-8, 12-14.

1980 *Carniodus carnulus* Walliser - Helfrich: Pl. 1, Figs. 1-6.

1981 *Carniodus carnulus* Walliser - Nowlan: Pl. 7, Figs. 8-11.

1981 *Carniodus carnulus* Walliser - Uyeno and Barnes: Pl. 1, Figs. 18, 19.

1982 *Carniodus carnulus* Walliser - Aldridge and Mohamed: Pl. II, Figs. 17-24.

1983 *Carniodus carnulus* Walliser - Uyeno *in* Uyeno and Barnes: p. 16, Pl. 5, Figs. 1-10.

1983 *Carniodus carnulus* Walliser - Mabillard and Aldridge: Pl. 2, Figs. 13, 14.

Diagnosis

Six skeletal elements make up the apparatus. Pa elements are short, slightly arched, with a large compressed cusp. Pb elements are thick, arched, marginal ledged blades with even triangular denticles and a small central cusp. M elements have a short main cusp with minor denticles on the posterior blade. The transition series consists of three form elements. The Sc has a long, narrow cusp with a small lateral process and a denticulated posterior process, the Sb a long, narrow cusp with a downward deflected denticulated anterior process and a denticulated posterior process, and the Sa is symmetrical, consisting of a narrow cusp and denticulated posterior process with two lateral processes.

Description

The elements assigned to *C. carnulus* were described by Walliser (1964).

Remarks

The six element reconstruction of the *C. carnulus* apparatus by Barrick and Klapper (1976) is confirmed by the Avalanche Lake collection.

Variation in Pa element morphology is within the end members illustrated for the form species by Walliser (1964). A number of specimens have small lateral processes,

similar to forms figured in Barrick and Klapper (1976) from the Clarita Formation, and Aldridge and Mohamed (1982) from Norway, indicating that this is not a local variation.

Two distinct forms of the Pb element are present in the collection. The first form is identical to the type species in the literature. The second form has expanded ledges, forming a platform, the denticles are similar to the types. On one specimen a small denticle on the platform is disjunct from the main blade. The elements associated with this Pb are identical to those of the apparatus with the unmodified Pb.

Range

At Avalanche Lake *Carniodus carnulus* apparently first occurs in the lowest horizon of *P. amorphognathoides*, but then is not found again until the upper *amorphognathoides* Zone. The modified Pb element is a later development within the species, occurring just before the last occurrence of *C. carnulus*.

Material studied

29 Pa, 59 Pb, 6 M, 11 Sc, 12 Sb, 7 Sa.

4.3 Family Pterospathodontidae Cooper, 1977b

4.3.1 Genus *Apsidognathus* Walliser, 1964

Type Species

1964 *Apsidognathus tuberculatus* - Walliser: p. 29-30, Pl. 5, Fig. 1; Pl. 12, Figs. 16-22; Pl. 13, Figs. 1-5.

Remarks

The multielement genus *Apsidognathus* probably is not complete as presently described. The skeletal assemblage is presently described with five distinct form elements: Pa_1, Pa_2, Pb_1, Pb_2, and Sa. Cones similar to *Pseudooneotodus* may also be part of the apparatus (Mabillard and Aldridge, 1983). See discussion under *A. tuberculatus*.

Apsidognathus tuberculatus Walliser, 1964

Plate 4, Figures 6-11

Pa_1 Element

1964 *Apsidognathus tuberculatus* - Walliser: p. 29-30, Pl. 5, Fig. 1; Pl. 12, Figs. 16-22; Pl. 13, Figs. 1-5.

Pa_2 Element

1964 *?Pygodus lenticularis* - Walliser: p. 67-68, Pl. 4, Fig. 17; Pl. 12, Fig. 15.

Pb_1 Element

1964 *Astrognathus tetractis* - Walliser: p. 30, Pl. 5, Fig. 4; Pl. 14, Fig. 1, 2.

Pb_2 Element

1964 *Ambalodus galerus* - Walliser: p. 27, Pl. 6, Fig. 1; Pl. 12, Figs. 1-7.

Sa Element

1964 *Pygodus lyra* - Walliser: p. 68, Pl. 5, Fig. 5; Pl. 12, Figs. 8-14.

Multielement

1972 *Apsidognathus tuberculatus* Walliser - Walliser: p. 76.

1975 *Apsidognathus tuberculatus* Walliser - Aldridge: Pl. 1, Figs. 1, 2.

1980 *Apsidognathus tuberculatus* Walliser - Helfrich: Pl. 1, Figs. 25, 29.

1981 *Apsidognathus tuberculatus* Walliser - Nowlan: Pl. 7, Figs. 7, 12-14, 17.

1981 *Apsidognathus tuberculatus* Walliser - Uyeno and Barnes: Pl. 1, Figs. 14-17.

1983 *Apsidognathus tuberculatus* Walliser - Uyeno *in* Uyeno and Barnes: p. 14-15, Pl. 6, Figs. 6-14.

Diagnosis

Apsidognathus tuberculatus is, at present, reconstructed from five form taxa first described by Walliser (1964). Characteristic of the five elements are broad shallow basal areas, and poorly developed (in relation to *Ozarkodina*) denticles, or nodes.

Description

The form elements and multielement description of a four element apparatus have been described in the literature. Walliser (1964) gave a complete description of the form elements.

Remarks

The form element *Ambalodus galerus* is here included in the apparatus of *A. tuberculatus*. The element is placed in the Pb position, designated Pb_2 in conjunction with the other Pb element *Astrognathus tetractis* s.f. Inclusion of *A. galerus* s.f. in *A. tuberculatus* was first proposed by Aldridge (1974), based on common occurrence and

morphology. *Apsidognathus ruginosus* has a five element apparatus, possibly including a cone element as well (Mabillard and Aldridge, 1983). Evolution of *Apsidognathus* from *Astropentagnathus* (see Mostler, 1967) further supports a five form element apparatus. *Astropentagnathus* is also composed of two Pa elements, two Pb elements, and a Sa(?) element.

The Pa element varies greatly from juvenile and between adult forms, largely in the length of the anterior blade, prominence of the six oral ridges, and extent of the interridge platform. The axial ridge is generally prominent, the lateral ridges are cryptic to prominent, with accessory ridges sometimes present. Specimens which could be assigned to *A. ruginosus* are included with *A. tuberculatus* due to the lack of sufficient distinctive elements to confirm the occurrence of the species at Avalanche Lake. These specimens, from three samples from two sections, consist of one Pb_1, one Pa_2, one Pb_2, and two Sa elements. Another Pa_1 element has the ornamentation of rugae on one lateral platform and tubercules on the other. Mabillard and Aldridge (1983) considered a more symmetrical Pa_1 element to be characteristic of *A. tuberculatus*, but the *A. ruginosus/tuberculatus* specimens are symmetric. In comparison, variation in the *A. tuberculatus* Pa_1's from Avalanche Lake range from symmetrical, laterally flared, and laterally thinned. From the specimens available, *A. ruginosus* can not be confirmed. Rugose ornamentation may be the result of intraspecific variation. Some *Aulacognathus* species in the collection also have an ornamentation of rugae.

Apsidognathus tuberculatus figured by Helfrich (1980) resembles *Apsidognathus walmsleyi* of Aldridge (1974), a multielement species which was only partially reconstructed. *Ozarkodina* n. sp. A of Helfrich may correspond to the Pb_2 position in the *Apsidognathus* apparatus, although the forms did not occur in the same samples.

Range

At Avalanche Lake *Apsidognathus tuberculatus* ranges through the *amorphognathoides* Zone. The specimens that may belong to *A. ruginosus* forms occur only in the upper *amorphognathoides* Zone.

Material studied

150 Pa_1, 12 Pa_2, 3 Pb_1, 40 Pb_2, 19 Sa.

Apsidognathus n. sp. A

Plate 4, Figure 12

Diagnosis

Only the Pa_1 element is recognized: amorphognathiform, tri- to pentalobate with four prominent denticulated ridges. Interridge areas and posterior lobe are covered with tubercules.

Description

Pa_1 element is tetralobate, the inner lateral lobe bifurcated or fused to the anterior lobe forming penta- to trilobate outlines. Four prominent ridges radiate from the central area into the anterior, posterior, and inner lobes. Ridges are denticulated and noncuspate. The outer lateral lobe is not distinctly ridged. The basal cavity is shallow, expanded under the entire aboral surface.

The remainder of the apparatus is unknown. Other elements are probably similar to, or indistinguishable from, elements of *Apsidognathus tuberculatus*.

Remarks

Apsidognathus n. sp. A evolved from *A. tuberculatus*. As described above, the denticulated ridges of *A.* n. sp. A correspond to the homologous ridges of *A. tuberculatus*. Forms of *A. tuberculatus* with only one pair of lateral ridges are intermediate to the type *A. tuberculatus* and *A.* n. sp. A.

Range

At Avalanche Lake *Apsidognathus* n. sp. A occurs in the upper *amorphognathoides* Zone.

Material studied

6 Pa_1.

4.3.2 Genus *Astropentagnathus* Mostler, 1967

Type Species

1967 *Astropentagnathus irregularis* - Mostler: p. 298-300, Pl. 1, Figs. 1-11.

Remarks

The multielement genus *Astropentagnathus* may be incompletely described at the present time. The type species is described with five distinct skeletal elements: Pa_1, Pa_2, Pb_1, Pb_2, and Sa. See the discussion under *A. irregularis*.

Astropentagnathus irregularis Mostler, 1967

Plate 2, Figures 2-7

Pa_1 Element

1967 *Astropentagnathus irregularis* - Mostler: p. 298-300, Pl. 1, Figs. 1-11.

Pa_2 Element

1967 *Spathognathodus tyrolensis* - Mostler: p. 302, Pl. 1, Figs. 17, 19, 20, 23.

Pb_1 Element

1971 *"Rhynchognathus"* n. sp. - Schönlaub: p. 48-49, Pl. 3, Figs. 15-19.

Sa Element

1971 *Falcodus?* n. sp. - Schönlaub: p. 47, Pl. 3, Figs. 1-3.

Multielement

1971 *Hadrognathus irregularis* (Mostler) - Schönlaub: p. 42-43, Pl. 1, Figs. 1-11.

1975 *Astropentagnathus irregularis* Mostler - Klapper and Murphy: p. 24-25, Pl. 1, Figs. 15-18.

1978 *Hadrognathus irregularis* (Mostler) - Miller: Pl. 4, Figs. 5-7.

Astropentagnathus irregularis Mostler - Uyeno *in* Uyeno and Barnes: p. 15, Pl. 4, Figs. 23, 24.

Diagnosis

The apparatus of *A. irregularis* consists of five discrete skeletal elements: Pa_1 which is amorphognathiform; Pa_2 amorphognathiform; Pb_1 rhynchognathiform; Pb_2 ozarkodiniform; Sa falcodiform. The Pa elements are diagnostic, the Pa_1 with five processes, the Pa_2 with three. The process margins are expanded into ledges, forming a platform. Denticles are short, laterally compressed, and of equal size.

Description

The Pa_1, Pa_2, Pb_1, and Sa elements have been described in the literature in form taxonomy, see Schönlaub (1971).

Pb_2 Element: The element is ozarkodiniform with an expanded basal cavity. Anterior denticles are fused nearly to the apex, shorter in the anterior portion, higher toward the cusp, which is posterior to the center. The posterior blade is shorter and lower than the anterior blade. Denticles are triangular and discrete in lateral profile. The lateral margins are expanded, roughly triangular, and excavated by the basal cavity. The greatest lateral projection is in the posterior half.

Remarks

The platform ledges and denticulation of the Pa elements suggests a relationship to *Pterospathodus*. Mostler (1967) discussed *A. irregularis* as the evolutionary predecessor of *Apsidognathus* and *Aulacognathus*. This evolution resulted in a reorientation and redefinition of processes, and a change in denticulation. No intermediate forms were recognized in the Avalanche Lake collection, where all three genera were recognized. The reconstruction of the *Astropentagnathus* apparatus does indicate a relationship to *Apsidognathus* which is also reconstructed with a five element apparatus of similar element arrangement. The greatest similarity is in the two Pb elements, while the Pa and Sa elements are quite different. Mirza (1976) reconstructed *A. irregularis* as a seven element apparatus. The two additional elements (Pb and M), not described here, were not recognized in the Avalanche Lake collection.

The Pa element illustrated by Pickett (1978) as *A. irregularis* appears to be *Aulacognathus kuehni*, where the lateral process of the minor longitudinal process is anteriorly fused. *Astropentagnathus irregularis* has not otherwise been reported from Australia.

Range

Astropentagnathus irregularis occurs in the *celloni* Zone and lowermost *amorphognathoides* Zone at Avalanche Lake.

Material studied

167 Pa_1, 85 Pa_2, 13 Pb_1, 10 Pb_2, 19 Sa.

Astropentagnathus aff. *A. irregularis* Mostler, 1967

Plate 2, Figure 8

Description

Single element form. Platform analogous to the Pa_1 of *A. irregularis*, but the processes are slim with greater twisting. The element is amorphognathiform with five processes which are slightly arched. The main process is anteriorly twisted. The outer lateral process is single, projecting anteriorly. The inner process is bifurcated. The denticulated ridges of the lateral processes are not fused with the ridge of the main process. Denticles are short, laterally compressed, and of uniform size. The basal cavity extends to the end of all the processes.

Remarks

The element is less robust than the Pa_1 of *A. irregularis*. The denticles of the bifurcated inner lateral process do not join with those of the main process, a characteristic of *Aulacognathus*. No other elements assignable to *Astropentagnathus* were found in the sample containing *A.* aff. *A. irregularis*.

Range

At Avalanche Lake *Astropentagnathus* aff. *A. irregularis* occurs at the base of the *celloni* Zone.

Material studied

5 elements.

4.3.3 Genus *Aulacognathus* Mostler, 1967

Type Species

1967 *Aulacognathus kuehni* - Mostler: p. 301, Pl. 1, Figs. 12-15, 21, 24, 25.

Remarks

The complete apparatus of the type species is undefined, probably sharing elements with other species. The genus and species are presently defined by a Pa element (amorphognathiform). A Pb element (ozarkodiniform) and M element (neoprioniodiform) have been described for *Aulacognathus bullatus bullatus*.

Aulacognathus bullatus bullatus (Nicoll & Rexroad, 1969)

Plate 3, Figures 1, 2

Pa Element

1969 *Neospathognathodus bullatus* - Nicoll and Rexroad: p. 44-45, Pl. 1, Figs. 5-7.

Pb Element

1964 *Ozarkodina* sp., ex. aff. *O. adiutricus* Walliser - Walliser: p. 54, Pl. 27, Fig. 11; Text-Fig. 7 n.

Multielement

1981 *Aulacognathus bullatus* (Nicoll & Rexroad) - Nowlan: Pl. 5, Figs. 20, 23, 24.

1983 *Aulacognathus bullatus* (Nicoll & Rexroad) - Uyeno *in* Uyeno and Barnes: p. 15, Pl. 4, Figs. 18, 20-22.

Diagnosis

The Pa element is modified spathognathodiform, Pb is ozarkodiniform. The Pa element consists of a main blade with an inner and outer lateral process. The processes are shorter than the anterior blade, at right angles to or deflected anteriorly, with irregular nodular denticles. The posterior process is deflected to the outer side.

Description

The Pa and Pb elements were described by Nicoll and Rexroad (1969). Nowlan (1981) illustrated a M element which was assigned to *A. bullatus*.

Remarks

Aulacognathus bullatus is recognized at Avalanche Lake in two subspecies, based on differences in the Pa element. *Aulacognathus bullatus bullatus* corresponds to the type element illustrated by Nicoll and Rexroad (1969). The nominate subspecies has relatively narrow lateral and posterior processes, sometimes bifurcated, with rounded nodules on the oral surface. This subspecies has been illustrated by Klapper and Murphy (1975) from Nevada, Schönlaub (1975) from Austria, and Nowlan (1981) and Uyeno and Barnes (1983) from Québec.

Aulacognathus was considered to have developed from *Astropentagnathus* by Mostler (1967), in reference to *A. kuehni*. The range of *A. irregularis* is coeval with *A. b. bullatus*, *A. kuehni* appearing right after the last occurrence of *Astropentagnathus irregularis*. The range of A. b. bullatus then continues past the extinction of *A. irregularis* and *A. kuehni*. Neither the range nor the morphology of the Pa element indicates that *A. b. bullatus* and its lineage are directly decended from *A. kuehni* (Fig. 13). A development from *Astropentagnathus* is not evident either.

Range

The range of *A. b. bullatus* at Avalanche Lake is from the base of the *celloni* Zone to the top of the *amorphognathoides* Zone.

Material studied

72 Pa, 36 Pb.

Aulacognathus bullatus n. ssp. A

Plate 3, Figure 3

Synonymy

1972 *Neospathognathodus bullatus* Nicoll & Rexroad - Aldridge: p. 196, Pl. 3, Fig. 15.

Diagnosis

The Pa element is diagnostic, the remainder of the apparatus is identical to that of *A. b. bullatus*. The Pa is modified spathognathodiform, consisting of an unarched, slightly bowed blade with compressed, closely spaced denticles. The posterior third of the blade is outwardly twisted and expanded into a platform. Inner and outer lateral processes extend outward near the middle of the blade. The two processes are anteriorly deflected, expanded into platforms with raised ridges that are disjunct from the main blade. The ridges are sharp and irregular, as on *A. b. bullatus*. The platforms are similar in size to the posterior platform, with irregular margins.

Description

The Pa element is similar to that of *A. b. bullatus*, except that the lateral and posterior processes are broadened into platforms with rounded ends. Denticles on the processes are discrete, irregular to triangular in shape or absent, replaced by short, sharp edged ridges or nodules. The process margins are irregular.

Remarks

Aulacognathus bullatus n. ssp. A has been previously illustrated as *A. bullatus* from California (Miller, 1975), and Great Britain (Aldridge, 1972).

Aulacognathus bullatus n. ssp. A bears some resemblance to *Aulacognathus latus*, but *A. latus* has more flattened lateral processes and lacks denticles on the oral surface. The specimen assigned to *A. latus* by Aldridge (1979) is similar in having reduced lateral platforms (see *A.* aff. *A. latus*). *Aulacognathus bullatus* n. ssp. A may represent a

transitional form toward *A. latus* or a separate lineage (Fig. 13).

Range

At Avalanche Lake *Aulacognathus bullatus* n. ssp. A occurs in the *amorphognathoides* Zone.

Material studied

17 Pa.

Aulacognathus kuehni Mostler, 1967

Plate 3, Figure 6

Synonymy

1967 *Aulacognathus kuehni* - Mostler: p.301, Pl. 1, Figs. 12-15, 21, 24, 25.

Diagnosis

Only the Pa element has been described, the Pb is similar to that of other aulacognathids. The Pa element consists of two longitudinal processes separated by a near central groove, moderately bowed. Each process has an anteriorly deflected lateral process. In some specimens, one of the lateral processes is fused to the main process. The processes are denticulated.

Description

The elements assigned to *A. kuehni* were described by Aldridge (1972).

Remarks

Specimens in the Avalanche Lake collection are like the forms illustrated by Aldridge (1972, 1975), or they lack a secondary process on the inner platform. Aldridge (1972) noted a morphological similarity between the "tuberculated ornamentation of the oral surface" of *A. kuehni* to *Astropentagnathus* (*A. irregularis*). Similarities in denticulation are not evident between these genera from Avalanche Lake. The denticles of *A. irregularis* are laterally compressed and angular (*Pterospathodus*-like) and the oral surface of *A. kuehni* is tuberculated, like *A. tuberculatus*. Evolution of *A. kuehni* from *A. irregularis* was suggested by Mostler (1967), though the similarity is from the general form of the elements and variation within the lateral processes, not the denticulation.

Range

Aulacognathus kuehni occurs in a narrow horizon within the lower *amorphognathoides* Zone at Avalanche Lake.

Material studied

10 Pa.

Aulacognathus aff. *A. latus* (Nicoll & Rexroad, 1969)

Plate 3, Figure 4

Synonymy

1979 *Aulacognathus latus* - (Nicoll and Rexroad) - Aldridge: p. 12, Pl. 1, Figs. 4, 5.

Description

Pa element: modified spathognathodiform consisting of a narrow slightly bowed blade with two anteriorly deflected lateral processes, and an outwardly deflected posterior process. The blade is denticulated with closely spaced laterally compressed denticles. The outer lateral process is expanded into a platform, rounded, with an irregular outline. Five to seven denticles are irregularly spaced on the platform. The inner edge is fused to the main blade. The inner lateral process is expanded into a platform, and is slightly smaller than the outer lateral process. The platform has three denticles, the edge fused to the main blade. The posterior process is expanded into a platform, tapering to a point. The process has four to five denticles. The basal cavity is excavated under the lateral processes and under the blade.

Remarks

Elements assigned to *A.* aff. *A. latus* from Avalanche Lake are identical to a specimen figured by Aldridge (1979) which was assigned to *A. latus*. These specimens lack the posterior lateral process of the holotype, and have pronounced denticles on the lateral platforms. Other specimens of *A. latus* figured in the literature are similar to the holotype (see Klapper and Murphy, 1975; Cooper, 1977b). *Aulacognathus* aff. *A. latus* is similar to *A. bullatus* n. ssp. A in the expansion of the lateral platforms, and dissimilar to the characteristic flaring and flattening of the holotype of *A. latus*. *Aulacognathus latus* of Aldridge (1979) and *A.* aff. *A. latus* may deserve separation from *A. latus* at the species level.

Range

At Avalanche Lake *Aulacognathus* aff. *A. latus* first occurs at the base of the *amorphognathoides* Zone, extending into the middle of the zone.

Material studied

5 Pa.

Aulacognathus n. sp. A

Plate 3, Figure 5

Diagnosis

The Pa element is the only part of the apparatus recognized. The Pa is modified spathognathodiform, consisting of a slightly bowed main blade with an outward deflected posterior process, and outer and inner anteriorly deflected lateral processes. The lateral processes flare anteriorly into wide platforms fused to the main blade.

Description

The main blade is slightly bowed and arched, the posterior one-fourth outwardly deflected at 45°. Denticles are short, laterally compressed, and slightly larger on the anterior portion. The outer and inner processes diverge from the posterior half of the blade, expanding and flattening, the inner portions fused to the anterior blade. The process ridges are denticulated, the outer ridge with three reduced denticles, and the inner ridge with three to five, larger, more closely spaced denticles. The basal cavity is shallow and widely expanded under the lateral processes, becoming a shallow groove under the anterior and posterior ends of the blade.

Remarks

Aulacognathus n. sp. A is quite similar to *A. latus* (the type species), but is distinct in the lack of a secondary, posteriorly oriented lateral process, and having denticles on the lateral processes (see Nicoll and Rexroad, 1969). *Aulacognathus latus* and *A.* n. sp. A are both thought to have developed from *A. bullatus*, the lateral processes fusing to the blade, where *A.* n. sp. A is the more primitive form with denticulated lateral processes. Another possibility is that *A.* n. sp. A may be a local variation of *A. latus*.

The Pb element of *A.* n. sp. A is indistinguisable from the Pb of other aulacognathids, and is included under the listing of *A. b. bullatus*.

Range

Aulacognathus n. sp. A occurs in the middle *amorphognathoides* Zone at Avalanche Lake.

Material studied

12 Pa.

Aulacognathus n. sp. B

Plate 3, Figure 7

Diagnosis

Only the Pa element is diagnostic, the Pb element is similar to the Pb of other aulacognathids. The Pa element is modified spathognathodiform, spade shaped in outline, consisting of an anterior blade, expanded, tuberculated lateral processes, and a widely expanded posterior process.

Description

The Pa consists of a slightly bowed blade with short, laterally compressed denticles. Lateral processes diverge from the posterior half, one on each side, deflected anteriorly. A posterior process is outwardly deflected. The processes, subequal in size, are expanded from a main ridge, the inner margins of the lateral processes fused to the blade. The process ridges are denticulated with low rounded tubercules, the process surfaces are tuberculated or finely ridged. The basal cavity is very shallow, expanded under the processes, forming a groove under the anterior blade.

The Pb element is indistinguishable from the Pb of *A. b. bullatus*.

Remarks

Aulacognathus n. sp. B is related to *A. bullatus*. *Aulacognathus* n. sp. B has developed expanded lateral processes and reduced relief on the oral surface. *Aulacognathus bullatus* n. ssp. A and *A.* aff. *A. latus* are possibly intermediate forms between *A. b. bullatus* and *A.* n. sp. B (Fig. 13). *Aulacognathus* n. sp. B differs from *A.* n. sp. A in being more robust, having a spade shaped outline rather than a bird shaped outline, and the denticulation of the lateral process surfaces. Two oral ornamentation types are present on the lateral processes, tubercles and small angular ridges. The small ridge ornamentation has been noted in other species as well, *A. b.* n. ssp. A and *A. tuberculatus*.

Pb elements are listed with the material of *A. b. bullatus*.

Range

Aulacognathus n. sp. B occurs in the upper *amorphognathoides* Zone at Avalanche Lake.

Material studied

18 Pa.

4.3.4 Genus *Pterospathodus* Walliser, 1964

Type Species

1964 *Pterospathodus amorphognathoides* - Walliser: p. 67, Pl. 6, Fig. 7; Pl. 15, Figs. 9-15.

Remarks

Multielement *Pterospathodus* is composed of at least four distinct skeletal elements: Pa, Pb, M, and a S transitional series. The Pa element is amorphognathiform or spathognathodiform; Pb is ozarkodiniform; M is neoprionodiform; S elements are variable, denticulated or undenticulated, triangular in shape, similar to neoprionodiform.

Pterospathodus amorphognathoides Walliser, 1964

Plate 4, Figures 1-3

Pa Element

1964 *Pterospathodus amorphognathoides* - Walliser: p. 67, Pl. 6, Fig. 7; Pl. 15, Figs. 9-15; Text-Fig. 1 f.

Pb Element

1964 *Ozarkodina gaertneri* - Walliser: p. 57, Pl. 6, Fig. 6; Pl. 27, Figs. 12-19; Text-Fig. 1 g.

M Element

1964 *Neoprioniodus triangularis triangularis* - Walliser: p. 52, Pl. 6, Fig. 13; Pl. 28, Figs. 25-30; Text-Fig. 6 d-f.

S Element

1964 *Neoprioniodus costatus costatus* - Walliser: p. 48-49, Pl. 6, Fig. 14; Pl. 28, Figs.

36-41; Text-Fig. 6 l-n.

Multielement

1971 *Pterospathodus amorphognathoides* Walliser - Schönlaub: p. 45, Pl. 2, Figs. 6-12.

1972 *Pterospathodus amorphognathoides* Walliser - Walliser: p. 76.

1974 *Pterospathodus amorphognathoides* Walliser - Aldridge: Text-Fig. 1 e, f.

1975 *Pterospathodus amorphognathoides* Walliser - Aldridge: Pl. 1, Figs. 22, 23.

1976 *Pterospathodus amorphognathoides* Walliser - Barrick and Klapper: 1p. 82, Pl. 1, Figs. 4, 9-11, 16.

1977b *Pterospathodus amorphognathoides* Walliser - Cooper: p. 1065-1066, Pl. 2, Figs. 3, 6.

1978 Apparatus "C" of Walliser - Miller: Pl. 4, Fig. 8-11.

1980 *Pterospathodus amorphognathoides* Walliser - Helfrich: Pl. 2, Figs. 17-19.

1982 *Pterospathodus amorphognathoides* Walliser - Aldridge and Mohamed: Pl. II, Figs. 13-16.

1983 *Pterospathodus amorphognathoides* Walliser - Mabillard and Aldridge: Pl. 2, Figs. 25-27.

Diagnosis

Four form elements have been recognized in the apparatus. The Pa element is diagnostic, consisting of an unarched, straight or slightly bowed blade with laterally compressed, fused denticles. The blades are expanded marginally, forming ledges. Two denticulated and ledged lateral processes diverge from near midlength on the inside of the blade, one deflected posteriorly, the other, longer process, deflected anteriorly. The denticles are laterally compressed and closely spaced.

Description

The apparatus of *P. amorphognathoides*, as presently recognized, has been described in the literature. A complete description of the form elements was given by Walliser (1964).

Remarks

The Pa and Pb elements of *P. amorphognathoides* are very variable within the species definition. In the literature and the Avalanche Lake samples, a number of the Pa elements do not have the marginal ledges of the holotype, assignment to *P.*

amorphognathoides being based on the bifurcated lateral process and the morphology of the other elements. A variation of the Pa element found at Avalanche Lake has the denticles of the lateral process disjunct from the denticles of the main blade.

The first confirmed occurrence of *Pterospathodus amorphognathoides* is at AV 1 336, but it is not abundant until AV 1 347.5 / AV 2 47. An older sample contains a *Pterospathodus* Pa element with a single denticle branched off the lateral process, but the Pb of *P. amorphognathoides* is not recognized in the sample. A Pa element similar to the above mentioned element was illustrated by Aldridge (1972) as *P. amorphognathoides*; however, Barrick and Klapper (1976) suggested that that element could better be assigned to *P. p. procerus*.

The apparatus of *P. amorphognathoides* is similar to that of other pterospathodids. The Pb, M, and S elements of *P. p. procerus* are indistinguishable from those of *P. amorphognathoides*, first suggested by Walliser (1964), and discussed by Barrick and Klapper (1976). The list of material studied of *P. amorphognathoides* includes the Pb, M and S elements of *P. p. procerus*, as well as the corresponding elements of *P. p.* n. ssp. A.

Range

The first occurrence of *P. amorphognathoides* defines the base of the *amorphognathoides* Zone, the species ranging to the end of the *amorphognathoides* Zone.

Material studied

75 Pa, 152 Pb, 48 M, 34 S.

Pterospathodus celloni (Walliser, 1964)

Plate 2, Figure 1

Pa Element

1964 *Spathognathodus celloni* - Walliser: p. 73-74, Pl. 4, Fig. 13; Pl. 14, Figs. 3-16; Text-Figs. 1 b, 7 b-f.

Pb Element

1964 *Ozarkodina adiutricis* - Walliser: p. 54, Pl. 4, Fig. 14; Pl. 27, Figs. 1-10; Text-Figs. 1 a, 7 h-m.

M Element

1964 *Neoprioniodus triangularis tenuirameus* - Walliser: p. 53, Pl. 4, Fig. 15; Pl. 28, Figs. 21-24; Text-Fig. 6 a-c.

S Element

1964 *Neoprioniodus costatus paucidentatus* - Walliser: p. 48-49, Pl. 4, Fig. 23; Pl. 28, Figs. 31-35; Text-Fig. 6 i-k.

Multielement

1971 *Spathognathodus celloni* Walliser - Schönlaub: p. 44-45, Pl. 2, Figs. 1-5.

1975 *Llandoverygnathus celloni* (Walliser) - Aldridge: Pl. 1, Figs. 20, 21.

1975 *Pterospathodus celloni* Walliser - Klapper and Murphy: p. 27-28, Pl. 2, Figs. 2, 3.

1976 *Pterospathodus celloni* Walliser - Barrick and Klapper: p. 82-83, Pl. 1, Figs. 3, 5.

1978 Apparatus "B" of Walliser - Miller: Pl. 4, Figs. 1-4.

1981 *Pterospathodus celloni* Walliser - Uyeno and Barnes: Pl. 1, Figs. 20, 21.

1983 *Pterospathodus celloni* Walliser - Uyeno *in* Uyeno and Barnes: p. 24, Pl. 5, Figs. 17, 18, 20-24.

Diagnosis

Multielement *P. celloni* consists of four skeletal elements (Pa, Pb, M and S transition). The Pa element is diagnostic, spathognathodiform, consisting of a slightly bowed, unarched blade. Denticles are laterally compressed and closely packed, larger and higher toward the center of the blade. A short, undenticulated lateral flare diverges from the outer side at the midlength of the element. A second, undenticulated inner lateral flare, slightly wider than the outer process, diverges from the posterior half of the element. The basal cavity is expanded under the flares and length of the blade. The Pa element is distinguished from other species of *Pterospathodus* by the lack of a denticulated lateral process. The only other species without a lateral process, *Pterospathodus siluricus* is more strongly bowed and has only a single marginal flare.

Description

Elements assigned to *P. celloni* were described by Walliser (1964).

Remarks

The reconstruction of the *P. celloni* apparatus, in its four element form, was proposed by Barrick and Klapper (1976). The apparatus was not substantiated by collections from the Clarita Formation, but from the documentation of the synonomyzed

elements in the collections of Walliser (1964) and Aldridge (1972). All of the elements of this reconstruction are recognized in the Avalanche Lake collection.

Walliser (1964) suggested that the M and S elements of *P. celloni* are the ancestors of the corresponding elements in *P. amporphognathoides*. This is consistent with the lineage of Pa and Pb elements proposed by Walliser (1964), where *P. amorphognathoides* is descended from *P. celioni*, with *P. pennatus* as an intermediate form.

The M and S elements of *P. celloni* are not abundant in comparison to the Pa and Pb elements in the Avalanche Lake collection. This is due to a lower number of M and S elements in the apparatus, and/or because of their smaller size and resultant loss.

Range

The first occurrence of *P. celloni* defines the base of the *celloni* Zone, *P. celloni* ranges into the middle *amorphognathoides* Zone at Avalanche Lake.

Material studied

173 Pa, 86 Pb, 15 M, 10 S.

Pterospathodus pennatus procerus (Walliser, 1964)

Plate 4, Figure 4

Pa Element

1964 *Spathognathodus pennatus procerus* - Walliser: p. 80, Pl. 15, Figs. 2-8; Text-Fig. 1 e.

Diagnosis

Only the Pa element is diagnostic, the Pb, M and S elements are identical to the same elements of *P. amorphognathoides*. *Pterospathodus pennatus procerus* differs from the other subspecies in the lateral profile and the reduction in size of the lateral flare opposite the single lateral process. In *P. p. procerus* the denticles on the end of the blade are higher than the center denticles; the lateral process is deflected anteriorly.

Description

Pa elements assigned to *P. p. procerus* have been described by Walliser (1964).

Remarks

In the juvenile stage, Pa elements of *P. p. procerus* are indistinguishable from those of *P. amorphognathoides*. The subspecies was first identified in a sample containing a questionable *P. amorphognathoides* specimen below where the species first becomes abundant.

Range

At Avalanche Lake *Pterospathodus pennatus procerus* first occurs in the *celloni* Zone, but only occurs in large numbers within the *amorphognathoides* Zone, ranging to the top of the *amorphognathoides* Zone.

Material studied

352 Pa.

Pterospathodus pennatus n. ssp. A

Plate 4, Figure 5

Diagnosis

The Pa element is diagnostic, the remainder of the apparatus is identical to that of *P. amorphognathoides*. The Pa element is spathognathodiform with platform ledges and a single, anteriorly deflected, inner lateral process.

Description

The Pa element consists of a main blade, the posterior end outwardly deflected. A lateral process, anteriorly deflected, diverges at midlength. Opposite the lateral process is a marginal flare, just anterior of the process-blade junction. Denticles on the element are short and laterally compressed, higher and more closely spaced on the anterior portion of the blade. The entire element has well developed platform ledges, with a raised lip around the ledge. The basal cavity extends the length of the blade, and under the lateral process, narrowing distally.

Remarks

Pterospathodus pennatus n. ssp. A has platform ledges and denticulation on the Pa element similar to *P. amorphognathoides*, differing in the lack of a secondary lateral process, the length of the anterior lateral process, and the expansion of the lateral flare. The Pa element of *P. p.* n. ssp. A differs from the corresponding element in *P. p. procerus* in the prominence of the marginal flare and the platform ledges. The lateral process is

also much longer in *P. p.* n. ssp. A. The Pb element of the three species and subspecies are identical.

Pterospathodus pennatus n. ssp. A is a development between *P. amorphognathoides* and *P. p. procerus*. Walliser (1964) proposed an evolutionary lineage between *P. amorphognathoides* and *P. p. procerus*, with more than one stage of development of *P. p. procerus*. *Pterospathodus pennatus* n. ssp. A is morphologically intermediate between *P. amorphognathoides* and *P. p. procerus*, but does not appear to be a stratigraphically intermediate species, as the form occurs in the upper *amorphognathoides* Zone. *Pterospathodus pennatus* n.ssp A probably represents a later lineage of development which has characteristics of both forms. Walliser (1964) inferred that *P. p. procerus* developed from *P. amorphognathoides* (see Walliser, 1964, Text-Fig. 1), although the series of *Pterospathodus pennatus* subspecies suggests the development of *P. amorphognathoides* and *P. p. procerus* from *P. p. pennatus*, or *P. amorphognathoides* from *P. p. procerus*. Whatever the lineage, *P. p.* n. ssp. A is a later form of *Pterospathodus*, closely related to *P. amorphognathoides* and/or *P. p. procerus*. This group of species has undergone complex mosaic evolution.

Range

Pterospathodus pennatus n. ssp. A occurs in the upper part of the *amorphognathoides* Zone at Avalanche Lake.

Material studied

122 Pa.

4.3.5 New Genus A

Type Species

New Genus A n. sp. A

Diagnosis

The apparatus of the type species and the associated species are incomplete. The type species has two platform elements which are recognized, Pa_1 and Pa_2. The Pa_1 is amorphognathiform, the Pa_2 is pygodiform. The Pa elements are slightly arched blades with lateral processes, the outer processes sometimes modified into a lateral platform.

The blades and lateral processes are denticulated. The process ledges and/or platform have crenulated edges. The basal cavity is shallow, extending under the blade, lateral processes, and expanded platform.

New Genus A n. sp. A

Plate 3, Figures 8-12

Pa_1 Element

1978 *Aulacognathus* n. sp. A - Miller: p. 340-341, Pl. 4, Figs. 19-21.

Diagnosis

Two elements of the apparatus are recognized, corresponding to the Pa_1 and Pa_2 positions. Elements unarched, the oral surface with raised ridges, the ridges denticulated or nodose. The Pa_1 is diagnostic, consisting of a slightly bowed denticulated blade with curved ends forming an open sigmoid. Two lateral processes diverge from the outer margin; and a shorter process extends from the inner side, in the posterior half of the blade. A narrow platform/ledge extends around the blade and processes, the edge is irregular and ridged.

Description

Pa_1 element: amorphognathiform, star shaped, consisting of a main blade and three lateral processes with expanded margins forming a platform. The main longitudinal process is slightly bowed, the ends curved in larger specimens. Denticles are short and laterally compressed, longer on the anterior blade. Three lateral processes diverge from the posterior blade, two processes opposite a shorter single process, all of which are denticulated in the same fashion as the main blade. The anterior lateral process is the longer, approximatley half the length of the main blade, and deflected anteriorly. The posterior lateral process diverges at a high angle to the main blade. The platform edges are usually finely ridged, particularly in the larger specimens. The basal cavity is shallow, extending under the platform and blades, but not reaching the the margins of the processes.

Pa_2 element: modified pygodiform, roughly triangular in shape. One margin is ridged, a second ridge extends from the point of the triangle to the middle of the transverse ridge, roughly bifurcating the platform. The ridges are denticulated or nodose.

The basal cavity is broad, most deeply excavated under the oral ridges, but not reaching the element margins, as in the Pa_1 element.

Remarks

The Pa_1 element of this species was figured by Mirza (1976) from a collection from the Canadian Arctic Islands, and by Miller (1978) from California. Miller (1978) placed the species in the genus *Aulacognathus*. The Pa_2 element of the apparatus was not recognized from either collection.

The species is placed in a new genus based on the morphological differences between it and any other species. Genera with possible affinities are *Apsidognathus*, *Astropentagnathus*, and *Aulacognathus*. The nature of the Pa_1 and Pa_2 elements suggests a relationship to the *Apsidognathus-Astropentagnathus* lineage (Fig. 15). The Pa_1 is similar in appearance to the corresponding element in *A. irregularis*, while the Pa_2 element is suggestive of the Pa_2 element of *Apsidognathus tuberculatus*. No intermediate forms were recognized directly linking N. Gen. A n. sp. A to any genus, but the two Pa element apparatus indicates a linkage to the *A. irregularis*/*A. tuberculatus* lineage (see Mostler, 1967). A later species of N. Gen. A, New Genus A n. sp. B is apparently decended directly from N. Gen. A n. sp. A (Fig. 15).

Range

New Genus A n. sp. A occurs in the *celloni* Zone and the lower *amorphognathoides* Zone.

Material studied

39 Pa_1, 19 Pa_2.

New Genus A n. sp. B

Plate 3, Figures 14, 15

Diagnosis

Only the Pa element is recognized, consisting of a slightly bowed blade with a short, straight denticulated inner lateral process opposite a wide, smooth topped outer marginal platform.

Description

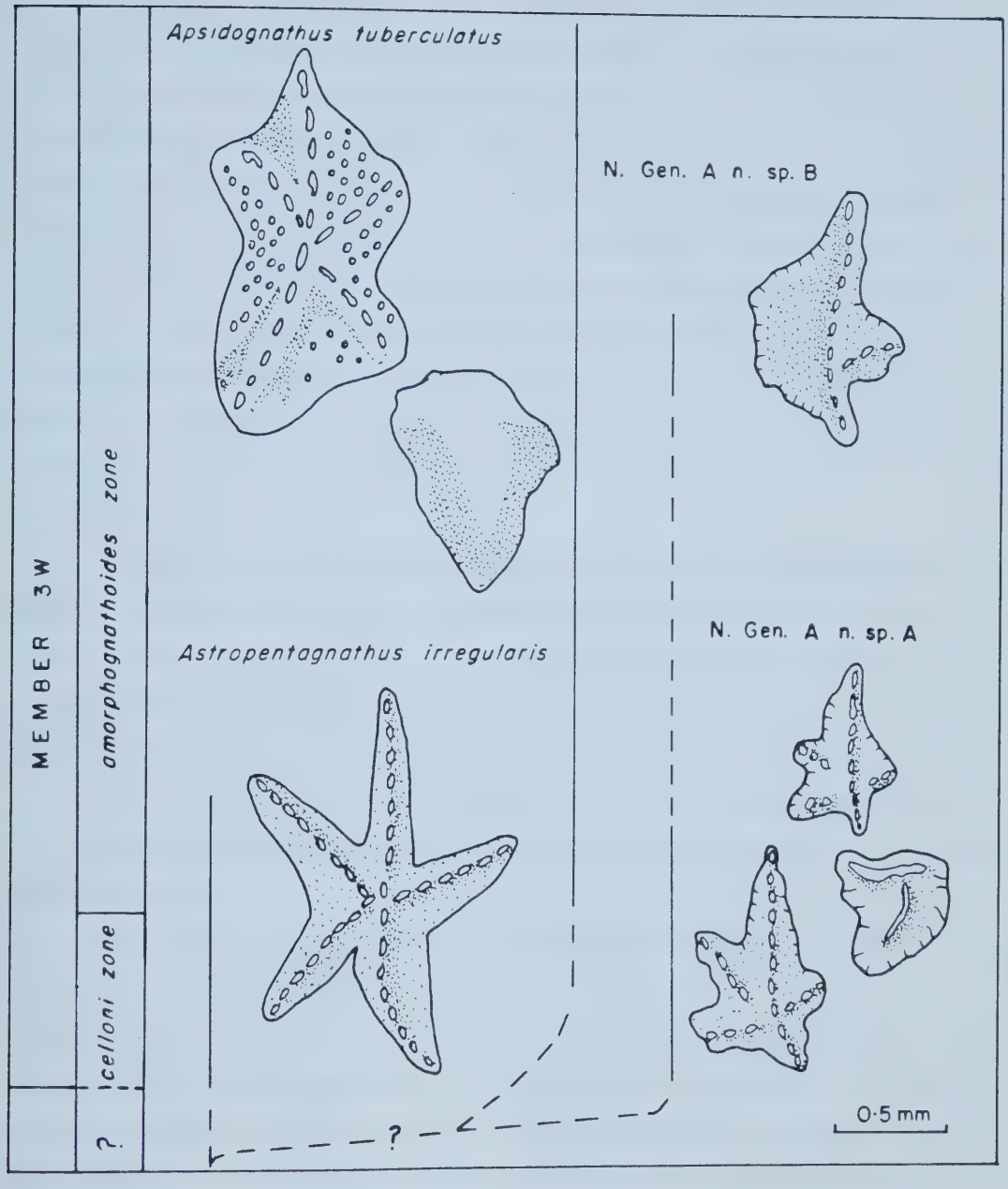

Figure 15 Development of Pa elements and stratigraphic range of *Apsidognathus tuberculatus*, *Astropentagnathus irregularis*, New Genus A n. sp. A, and New Genus A n. sp. B. New Genus A probably developed from the *Astropentagnathus-Apsidognathus* lineage. The solid lines show the stratigraphic range.

The element is modified amorphognathiform. The blade is slightly bowed, with partially fused denticles becoming totally fused posteriorly. An inner lateral process, with two to three denticles, diverges at a high angle from the blade, posterior to the midlength. The other side of the blade consists of a wide platform, which extends nearly the length of the blade. The platform is narrow in the anterior portion of the element, widening posteriorly before ending abruptly before the end of the blade. The outer margin, in the posterior half of the element, is sub-parallel to the blade, giving a square corner to the platform. The outer edge of the platform is crenulated. and slightly raised. The basal cavity is shallow, widely flared posteriorly, extending to the margins around most of the element. The basal pit is located under the junction between the inner lateral process and the blade.

Remarks

This species is placed in N. Gen. A because of the probable development of the species from N. Gen. A n. sp. A. This relationship is indicated by specimens of N. Gen. A n. sp. A with the dual lateral process of the Pa_1 element largely fused. If this fusion continues, the lateral processes become an outer platform. New Genus A n. sp. B is a further development, where the platform is smooth with no remnant of the lateral processes (Fig. 15). Other similarities between N. Gen. A n. sp. B and N. Gen. A n. sp. A are the short single inner lateral process, the style of denticulation, and the crenulation on the element edges.

New Genus A has characteristics of *Astropentagnathus* and *Apsidognathus*; *Apsidognathus* developing from *Astropentagnathus* (Mostler, 1967). As presently recognized, N. Gen. A n. sp. B can not be traced back to either genus. A specimen figured by Nicoll and Rexroad (Pl. 6, Fig. 15, 1969) as "Genus and species indeterminate" appears to be similar to N. Gen. A n. sp. B, having an expanded outer margin and a single inner process. This specimen was collected from the Lee Creek Member of the Brassfield Limestone, associated with *D. kentuckyensis*. The occurrence of this specimen with *D. kentuckyensis* makes it older than N. Gen. A n. sp. B, which is associated with an *amorphognathoides* fauna.

Range

New Genus A n. sp. B occurs in the middle of the *amorphognathoides* Zone at Avalanche Lake.

Material studied

6 Pa.

4.4 Family Distomodontidae Klapper, 1981

4.4.1 Genus *Distomodus* Branson & Branson, 1947

Type Species

1947 *Distomodus kentuckyensis* - Branson and Branson: p. 553, Pl. 81, Figs. 21-23, 27, 29-33, 36-41.

Remarks

Multielement *Distomodus* is composed of six distinct skeletal elements (Cooper, 1975): Pa, Pb, M, Sc, Sb, and Sa. The Pa element is icriodiniform; Pb is modified ambalodontiform; M is distomodiform; Sc is ligonodiniform; Sb is zygognathiform; Sa is trichonodelliform.

Distomodus kentuckyensis Branson & Branson, 1947

Plate 1, Figures 27-31

Pa Element

1947 *Icriodina irregularis* - Branson and Branson: p. 551, Pl. 81, Figs. 3-11, 18, 19.

Pb Element

1947 *Drepanodus simplex* - Branson and Branson: p. 522, Pl. 81, Figs. 24-26; Pl. 82, Fig. 38.

M Element

1947 *Distomodus kentuckyensis* - Branson and Branson: p. 553, Pl. 81, Figs. 21-23, 27, 29-33, 36-41.

Sc Element

1964 *Ligonodina egregia* - Walliser: p. 40, Pl. 6, Fig. 5; Pl. 32, Figs. 3, 4.

Sb-Sa Element

1947 *Trichonodella brassfieldensis* - Branson and Branson: p. 551, Pl. 81, 12-17; Pl.

82, Fig. 47.

Multielement

1975 *Distomodus kentuckyensis* Branson & Branson - Cooper: p. 998-1000, Pl. 2, Figs. 6, 8, 10, 11, 13, 14.

1981 *Distomodus kentuckyensis* Branson & Branson - Nowlan: Pl. IV, Figs. 22-26.

1982 *Distomodus kentuckyensis* Branson & Branson - Aldridge and Mohamed: Pl. I, Figs. 1-10.

Diagnosis

An assemblage of robust elements: Pa, Pb, M, and a transition series of ramiform elements assigned to Sc and Sb-Sa positions. The Pa element is icriodiniform, cruciform in outline, the lateral processes straight or slightly twisted, and perpendicular to the main blade or slightly deflected.

Descripton

The elements assigned to *D. kentuckyensis* have been described by Rexroad (1967).

Remarks

The elements of *D. kentuckyensis* are quite variable. The main longitudinal process of the Pa element can be straight, bowed, and/or slightly twisted. The position of the lateral processes can be perpendicular to the main process, anterior to lateral, or one anterior and one posterior to lateral (see Rexroad, 1967). The type specimens of Branson and Branson (1947) do not have lateral processes, possibly due to breakage of the specimens. The Avalanche Lake Pa elements have perpendicular and slightly deflected lateral processes on slightly bowed or straight blades. The Pa elements illustrated by Aldridge and Mohamed (1982) from Norway have the lateral process deflected at 45° to the main process. A new species of *Distomodus* illustrated by Nowlan (1983) from Anticosti Island is similar to *D. kentuckyensis*, but has only one long lateral process, the other process replaced by a small, undenticulated protuberance.

Development of the lateral-posterior processes on the distomodiform (M) element is not well illustrated in the literature. Denticulation of the processes was described by Rexroad (1967), though a complete specimen was not figured. Specimens figured in other studies are incomplete (see Synonymy) or have undenticulated lateral-posterior

processes (Aldridge and Mohamed, 1982). Specimens collected at Avalanche Lake have denticles on both lateral-posterior processes, as well as the posterior blade.

The S transition series elements are typical of specimens of *D. kentuckyensis* in the literature. The Sb-Sa designation is used because of the lack of a symmetrical element in the apparatus.

Distomodus kentuckyensis is the predecessor of *D. staurognathoides*, which appears in the middle Llandovery. The S elements of *D. kentuckyensis* have long, denticulated, posterior-lateral bars like *D. staurognathoides*, but were not found to develop expanded bars and platforms as do some late forms of *D. staurognathoides*.

Range

The first occurrence of *D. kentuckyensis* is used to define the base of the *kentuckyensis* Zone of the North American conodont zonation. *Distomodus kentuckyensis* is first recognized in the Avalanche Lake collection 3 m below the first occurrence of *I. discreta*, and 9 m below the first occurrence of *O? nathani*, defining the base of the *discreta/kentuckyensis/nathani* Zone, although a Pa element was not found at this horizon. All specimens assigned to *D. kentuckyensis* occur within the *discreta/kentuckyensis/nathani* Zone.

Material studied

10 Pa, 7 Pb, 5 M, 7 Sc, 15 Sb-Sa.

Distomodus staurognathoides (Walliser, 1964)

Plate 2, Figures 9-20

Pa Element

1964 *Hadrognathus staurognathoides* - Walliser: p. 35, Pl. 5, Fig. 2; Pl. 13, Figs. 6-15.

Pb Element

1969 *Trichonodella? expansa* - Nicoll and Rexroad: p. 64, Pl. 4, Figs. 19-22.

M Element

1972 *Distomodus kentuckyensis* Branson & Branson - Rexroad and Nicoll: Pl. 2, Fig. 46.

Sc Element

1964 *Ligonodina egregia* - Walliser: p. 40-41, Pl. 6, Fig. 5; Pl. 32, Figs. 3, 4.

Sb Element

1964 *Roundya caudata* - Walliser: p. 70, Pl. 5, Fig. 9; Pl. 31, Figs. 18, 19.

Sa Element

1972 *Exocognathus brassfieldensis* Branson & Branson - Rexroad and Nicoll: Pl. 2, Fig. 23.

"Johnognathus" Element

1977 *Johnognathus huddlei* - Mashkova: p. 129-131, Figs. 1, 2.

Multielement

1975 *Distomodus kentuckyensis* Branson & Branson - Klapper and Murphy: p. 46-47 [Pb, M, Sc-Sa elements].

1975 *Hadrognathus staurognathoides* Walliser - Schönlaub: p. 53-56, Pl. 1, Figs. 1-4, 17, 20, 23; Pl. 2, Figs. 1-10, 12-21.

1976 *Distomodus staurognathoides* (Walliser) - Barrick and Klapper: p. 71-72, Pl. 1, Figs. 20-28.

1977b *Hadrognathus staurognathoides* Walliser - Cooper: p. 1066-1067, Pl. 1, Figs. 1, 5-7, 12, 16.

1979 *Distomodus staurognathoides* (Walliser) - Aldridge: Pl. 1, Figs. 16, 17.

1981 *Distomodus staurognathoides* (Walliser) - Nowlan: Pl. 5, Figs. 21, 27; Pl. 6, Fig. 21.

1982 *Distomodus staurognathoides* (Walliser) - Aldridge and Mohamed: Pl. II, Figs. 1-6.

1983 *Distomodus staurognathoides* (Walliser) - Uyeno *in* Uyeno and Barnes: p. 17, Pl. 3, Figs. 1-15.

1983 *Distomodus staurognathoides* (Walliser) - Mabillard and Aldridge: Pl. 1, Figs. 15-20.

Diagnosis

The apparatus of *D. staurognathoides* is composed of six to seven form elements: Pa, Pb, M, Sc, Sb, Sa, and sometimes a secondary platform. The Pa element is characterized by five broad radiating processes, four subequal in length and a longer process with a denticulated blade on the end. The processes are covered with tubercles and ridges. The Pb, M and S elements are dominated by a large, curved cusp, with denticulated processes diverging from the cusp base.

Description

Elements assigned to *D. staurognathoides* have been described in the literature. The most complete descriptions are given with the type elements. Barrick and Klapper

(1976) figured the entire apparatus.

Remarks

Distomodus staurognathoides, as described in previous studies, consists of six elements assigned to the Pa, Pb, M, and S positions. The Pa element is very variable, the Avalanche Lake collection containing elements similar to those illustrated by Walliser (1964), Nicoll and Rexroad (1969), and Barrick and Klapper (1976). The variation is in the length and width of the processes and orientation of their divergence. The trend through time is for the platfoms to be wider and the element less spidery and symmetrical, though no typical form dominates any stratigraphic level in the collection.

The Pb and S transition series elements change through time, with the possibility of the addition of a new element within the apparatus. The lateral and posterior processes of the Pb element in younger forms are longer and have a greater development of denticles on the short platforms. This same development is evident in younger forms of the S elements. In the oldest samples of *D. staurognathoides* the posterior process of the Sa element, in particular, is a long denticulated bar. In younger samples these bars are expanded into platforms, though still attached by a narrow portion of the bar to the cusp. Easily fractured, these platforms have been referred to as a separate genus and species, *Johnognathus huddlei*.

"*Johnognathus*" elements have the characteristic denticulation and marginal ridging on the platform that is found on the long process of the Pa element and processes of the Pb element. Placement of the "*Johnognathus*" elements within the apparatus of *D. staurognathoides* is not always obvious because the appropriate elements are frequently broken. The bilaterally symmetrical form of "*Johnognathus*", such as the type specimen of Mashkova (1977), were probably associated with the S elements. The occurrence of unbroken elements of "*J. huddlei*" in the Avalanche Lake collection and in the literature can be explained in a number of ways. One possibility is that during life the long S-"*Johnognathus*" element broke, or the narrow bar degenerated, leaving the "*Johnognathus*" element discrete, possibly with a rudimentary anterior process (Fig. 16). A second possibility is that the "*Johnognathus huddlei*" element became disassociated from the S element through time, developing as a discrete element.

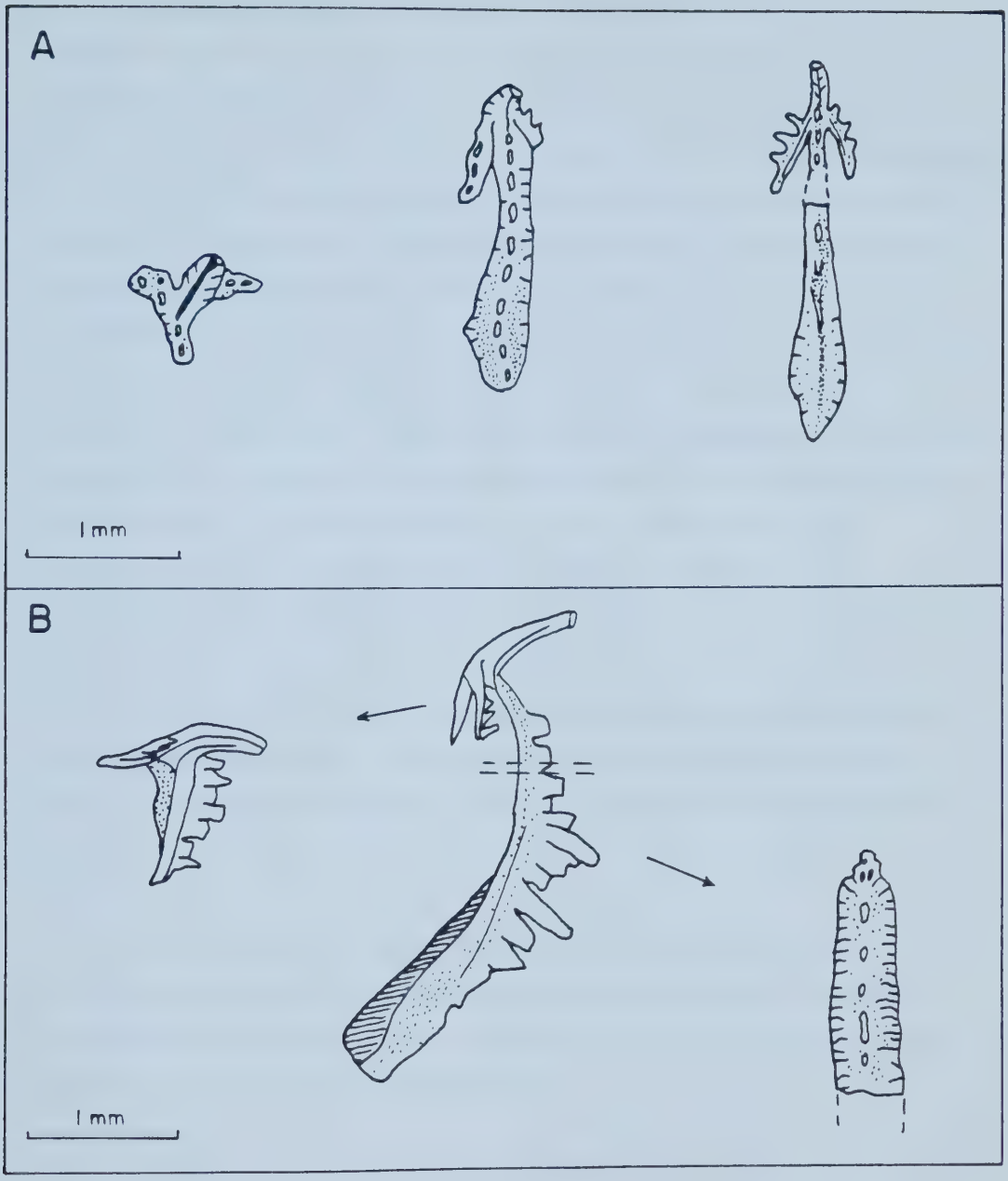

Figure 16 Elements of *D. staurognathoides* and the relationship of *"Johnognathus"* elements. **A** - *"Johnognathus"* forms attached to Pb and Sa elements, and a possible broken set. **B** - Development of discrete elements in assemblage. Large elements could break, subsequent mending forms two "whole" elements.

Mashkova (1977) suggested that the *J. huddlei* occupied the axial position between the sinistral and dextral elements of an apparatus composed of *Pterospathodus*, *Apsidognathus*, *Distomodus*, *Carniodus* and *Kockelella* (*P. amorphognathoides*, *A. tuberculatus*, *D. staurognathoides*, *C. carnulus*, and *K. ranuliformis*, Uyeno *in* Uyeno and Barnes, 1983). All of these species occur in the Avalanche Lake collection, but their ranges are not complementary to such an apparatus, nor was *J. huddlei* recognized in *amorphognathoides* Zone collections from the United States or the European Alps.

Elements of *Johnognathus* are included with *D. staurognathoides* on the bases of morphological similarity and actual life fusion of elements. The absence of "*Johnognathus*" elements from the United States and the European Alps indicates that the development of the "*Johnognathus*" element was not ubiquitous, but a regional variety of *D. staurognathoides*. Previous records of *J. huddlei* and associated forms (?"*Johnognathus huddlei*" of Uyeno and Barnes, 1983), are limited to an area encompassing Podolia, Scandinavia, Great Britain, Québec, and northern Canada. With the exception of the older occurrence of ?"*J. huddlei*" Uyeno in the *inconstans* Zone (= *celloni* Zone) from Anticosti Island, "*Johnognathus*" elements have only been recorded in the *amorphognathoides* Zone. The occurrence of "*Johnognathus*" elements in only younger *D. staurognathoides* samples indicates that it was a late development within the species.

Range

At Avalanche Lake the first appearance of *D. staurognathoides* is in the *celloni* Zone, the species ranging to the end of the *amorphognathoides* Zone. *Distomodus staurognathoides* with the "*Johnognathus*" elements first occurs in the collection as fragments in the middle *amorphognathoides* Zone.

Material studied

68 Pa, 37 Pb, 40 M, 82 Sc, 21 Sb, 34 Sa, 30 "*Johnognathus*".

SUPERFAMILY PANDERODONTACEA Lindström, 1970

4.5 Family Panderodontidae Lindström, 1970

Remarks

Barrick (1977) applied part of the element naming scheme (M and S transition series) of Sweet and Schönlaub (1975) to simple cone genera, including those in the Panderodontidae. This element naming scheme is not suitable for simple cone taxa, where the apparatus arrangement and number of elements was probably different from that of the pectiniform and ramiform element apparatuses that the scheme was proposed for. The panderodontids are presently under review by Jeppsson (see Jeppsson, 1983) and the proposal of a new naming scheme is probable. The simple cone naming scheme of Barrick (1977) is used in reference to the literature when discussing the multielement species.

4.5.1 Genus *Belodella* Ethington, 1959

Type Species

1940 *Belodus devonicus* - Stauffer: p. 420, Pl. 59, Figs. 47, 48.

Remarks

Multielement *Belodella* is considered to have a four element apparatus, with M, Sc, Sb and Sa elements (Barrick, 1977). The M element is slightly curved and nondenticulate; the Sc-Sa elements are belodelliform. The apparatus reconstructed from elements recovered at Avalanche Lake differs from the definition of Barrick (1977). The apparatus has a paired four element apparatus, in a transition series without a nondenticulated element. The reconstruction is similar to a coprolitic assemblage described by Lange (1968) of Late Devonian age, where the elements are paired, though the assemblage was incomplete. The Avalanche Lake species lack a symmetrical or nondenticulated element; and appear to be composed of four distinct elements in a transition series.

Belodella sp. A Miller, 1978

Plate 3, Figures 18, 19, 24, 25

Synonymy

1978 *Belodella* n. sp. A - Miller: p. 34, Pl. 1, Figs. 19-23.

Diagnosis

Elements are compressed, curved, twisted cones with sharp, laterally compressed denticles on the posterior (oral) surface. The denticles closest to the apex are distinctly longer than the more basal denticles. A transition series from short elements to long elements with the number of costae varying is present. This series corresponds to a Sc-Sb transition (Barrick, 1977) in other cone apparatuses.

Description

The elements are similar in general form and are described together. Characteristics which differentiate the elements are listed below. The different elements are given letter designations: a, b, c, d. This different designation is used because of the dissimilarity to established nomenclature of the elements and lack of a symmetrical element.

The cones are thin walled, laterally compressed, with a narrow basal cavity. They are recurved and twisted approximately two-thirds from the base. The basal cavity is deep, extending to the point of curvature. The base is wide, with a greater extension of the posterior portion, in the fashion of *Panderodus*, tapering uniformly to the point of curvature, then tapering rapidly to a long, narrow cusp. Denticles, located on the posterior surface, are small, laterally compressed, closely spaced and fused on the lower half of the cone. The upper denticles are longer, fused only at the base, curved inward, and almost as long as the cusp.

Form a: short cone, relatively wide base, costa on the outer surface is reduced or absent, one costa on inner surface.

Form b: short cone, relatively wide base, two costae on inner and outer surface.

Form c: long cone, two costae on inner and outer surface.

Form d: long cone, one costa on inner surface and outer surface.

Remarks

The specimens of *Belodella* that Miller (1978) assigned to *Belodella* n. sp. A are similar to the Form a and Form b of the Avalanche Lake collection. Other Silurian specimens of *Belodella* in the literature differ in that the base of the elements are flat, and/or lack costae (Rexroad and Craig, 1971; Pollock and Rexroad, 1973; Barrick, 1977). *Belodella anomalis* Cooper has denticles on the anterior surface of the cone (Cooper,

1974).

The form of the *Belodella* element is suggestive of a jaw, the presence of dextral and sinistral elements in the apparatus indicating paired mandibles. In comparison the related element of an Ordovician genus, *Belodina*, has been morphologically compared to a modern arachinid grasping apparatus (Müller *in* Robison (ed.), 1981). A paired apparatus of eight elements is suggested for the Silurian *Belodella* apparatus, functioning as a grasping or selective filtering apparatus (Fig. 17).

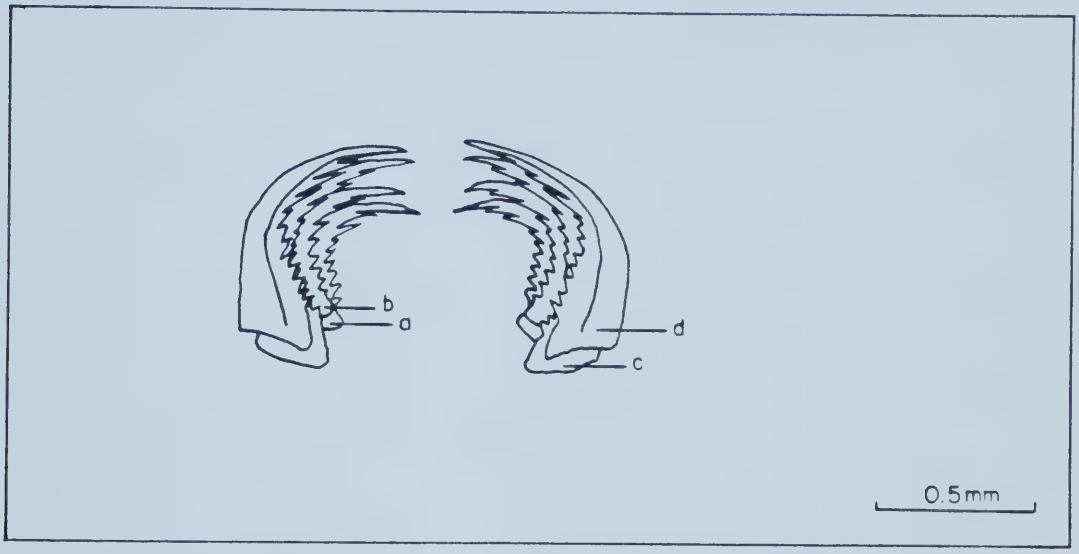

Figure 17 Dorsal view of possible eight element apparatus of *Belodella* sp. A. Letters correspond to form elements in the apparatus.

Range

Belodella sp. A occurs in the *amorphognathoides* Zone at Avalanche Lake.

Material studied

64 elements.

4.5.2 Genus *Panderodus* Ethington, 1959

Type Species

1933 *Paltodus unicostatus* - Branson and Mehl: p. 42, Pl. 3, Fig. 3.

Remarks

1974).

The form of the *Belodella* element is suggestive of a jaw, the presence of dextral and sinistral elements in the apparatus indicating paired mandibles. In comparison the related element of an Ordovician genus, *Belodina*, has been morphologically compared to a modern arachinid grasping apparatus (Müller *in* Robison (ed.), 1981). A paired apparatus of eight elements is suggested for the Silurian *Belodella* apparatus, functioning as a grasping or selective filtering apparatus (Fig. 17).

Figure 17 Dorsal view of possible eight element apparatus of *Belodella* sp. A. Letters correspond to form elements in the apparatus.

Range

Belodella sp. A occurs in the *amorphognathoides* Zone at Avalanche Lake.

Material studied

64 elements.

4.5.2 Genus *Panderodus* Ethington, 1959

Type Species

1933 *Paltodus unicostatus* - Branson and Mehl: p. 42, Pl. 3, Fig. 3.

Remarks

Multielement *Panderosus* consists of four panderodiform elements, a non-costate element (M), and three costate elements in a transition series (Sc, Sb, Sa), (Barrick, 1977). The M element is biconvex; Sc is unicostate to biconvex; Sb is bicostate to unicostate; Sa is symmetrical and bicostate.

Remarks

The genus *Panderodus* is presently under review, and a monograph in preparation by Jeppsson (Jeppsson, 1983). With this publication pending, the species recognized in the Avalanche Lake collection are only assigned based on general appearance and not identified to element assignments within the apparatus.

Panderodus unicostatus (Branson & Mehl, 1933)

Plate 3, Figures 20, 21

M Element

1933 *Paltodus simplex* - Branson and Mehl: p. 42, Pl.3, Fig. 4.

Sb Element

1933 *Paltodus unicostatus* - Branson and Mehl: p. 42, Pl.3, Fig. 3.

Sc Element

1971 *Panderodus* n. sp. - Rexroad and Craig: p. 698, Pl. 81, Figs. 26, 27.

Multielement

1976 *Panderodus unicostatus* (Branson & Mehl) - Cooper: p. 213, Pl. 1, Figs. 1-7, 22.

1977 *Panderodus unicostatus* (Branson & Mehl) - Barrick: p. 56-57, Pl. 3, Figs. 1, 2, 5, 6.

1978 *Panderodus unicostatus* (Branson & Mehl) - Rexroad, et al: p. 11, Pl. 1, Figs. 6-8.

1979 *Panderodus unicostatus* (Branson & Mehl) - Aldridge: Pl. 2, Figs. 17-22.

1983 *Panderodus unicostatus* (Branson & Mehl) - Uyeno *in* Uyeno and Barnes: p. 22-23, Pl. 9, Figs. 17-22.

Diagnosis

Elements are high, slender and gently curved. A single costa on either side of the elements extends from the base to past the interval of main curvature. The base is uneven, the posterior half lower than the front. The basal cavity extends to just past halfway up the element.

Description

The elements assigned to *P. unicostatus* have been described by Cooper (1976).

Remarks

Two distinct forms of *P. unicostatus* are common in the Avalanche Lake collection; slender elements, and more robust, thicker walled elements. Both forms were discussed by Barrick (1977), and included in *P. unicostatus*, though here the large forms have been listed under *Panderodus* spp. Elements have not been placed in the apparatus nomenclature of Barrick (1977), though the forms are recognized, based on the assumption that the system of nomenclature for this genus will be changed (see Jeppsson, 1983).

Range

At Avalanche Lake species assigned to *P. unicostatus* occur from the Ordovician-Silurian boundary to the youngest horizon collected.

Material studied

1084 elements.

Panderodus spp.

Plate 3, Figures 17, 22, 23

Remarks

Elements assigned to the genus *Panderodus* but not identified to the species level are left in open nomenclature. Included in this designation are specimens possibly assignable to *Panderodus recurvatus* (Rhodes), *Panderodus spasovi* Drygant, and large elements similar to *P. unicostatus*, which Cooper (1976) and Barrick (1977) included in *P. unicostatus*.

Material studied

425 elements.

4.5.3 Genus *Walliserodus* Serpagli, 1967

Type Species

1947 *Acodus curvatus* - Branson and Branson: p. 554, Pl. 81, Fig. 20.

Remarks

Multielement *Walliserodus* has a five element apparatus, consisting of a M element and a four element transition series Sd-Sa (Barrick, 1977). The M element is acodontiform; Sd-Sa elements are paltodontiform; Sd symmetrical biconvex; Sc asymmetrical biconvex; Sb asymmetrical triangular; Sa symmetrrical triangular. Elements of *Walliserodus* are recognized by the basal cross-section, which is roughly rectangular in outline.

Walliserodus sancticlairi Cooper, 1976

Plate 2, Figure 21

Pl. 1, Figs. 1, 2.

Multielement

1976 *Walliserodus sancticlairi* - Cooper: p. 214-215, Pl. 1, Figs. 8-11, 16-21.

1977 *Walliserodus sancticlairi* Cooper - Barrick: p. 59, Pl. 1, Figs. 11, 13-20.

1978 *"Walliserodus curvatus"* of Cooper, 1975 - Miller: Pl. 1, Figs. 10-17.

1978 *Walliserodus curvatus* (Branson & Branson) - Rexroad *et al.*: p. 12, Pl. 1, Figs. 1-5.

Diagnosis

The elements are strongly recurved with thick walls, anterior and posterior keels, wide bases, and sharp cusps. The *"curvatus"* element lacks costae on the inner lateral surface. Other elements are indistinguishable from the elements of *Walliserodus curvatus* (Branson & Branson).

Description

Elements assigned to *W. sancticlairi* have been described by Cooper (1976).

Remarks

No elements of *W. curvatus* were identified. Elements of *Walliserodus* found in association with *"curvatus"* elements belonging to *W. sancticlairi* were included with that species. Elements not associated with a *"curvatus"* element were left in open nomenclature, designated *Walliserodus* spp.

Range

At Avalanche Lake *W. sancticlairi* occurs in the *discreta/kentuckyensis/nathani* Zone.

Material studied

46 elements, 52 assigned to *Walliserodus* spp.

SUPERFAMILY HIBBARDELLACEA Müller, 1956

4.6 Family Hibbardellidae Müller, 1956

4.6.1 Genus *Oulodus* Branson & Mehl, 1933

Type Species

1930 *Cordylodus serratus* - Stauffer: p. 124, Pl. 10, Fig. 7. [= senior subjective synonym of *Oulodus mediocris* Branson & Mehl]

Remarks

Multielement *Oulodus* is composed of six distinct skeletal form elements (Sweet and Schönlaub, 1975; Sweet *in* Ziegler (ed.), 1981): Pa, Pb, M, Sc, Sb, and Sa. The Pa element is oulodiform, Pb is vacant or oulodiform in the type species, prioniodiniform in later species; M is cyrtoniodiform in early species, prioniodiform or neoprioniodiform in later species; Sc is cordylodiform or ligonodiniform; Sb is zygognathiform or "greilingiform", Sa is trichonodelliform. (See Sweet and Schönlaub, 1975 for a review of the genus.)

Three Silurian species recognized in the Avalanche Lake collection are questionably placed in *Oulodus*: *Oulodus? fluegeli*, *Oulodus? kentuckyensis*, and *Oulodus? nathani* because of the nature of the elements and their questionable evolution from Ordovician *Oulodus*. New species were also assigned to *Oulodus?*.

Oulodus? fluegeli (Walliser, 1964) group

Diagnosis

Pa element - lonchodiniform or diadelognathiform, Pb element - modified ozarkodiniform, M element - neoprioniodiform, Sc element - ligonodiniform, Sb element - modified trichonodelliform, Sa element - trichonodelliform. In two of the species, transition elements are recognized, most closely corresponding to Pa-Sa, Sc-Sb, and Sb-Sa.

Remarks

Oulodus fluegeli was questionably assigned to *Oulodus?* because of the laterally compressed and closely spaced denticles characteristic of the elements, unlike the typical peg shaped denticles of *Oulodus*.

A number of separate species have been grouped into *Oulodus? fluegeli* in the literature. The elements of these species are commonly similar, but the ranges, and differences in the elements indicates that several separate species should be proposed. The *Oulodus? fluegeli* group specimens from Avalanche Lake are placed in three species. These species have elements very similar to specimens previously described in the literature as *O? fluegeli* (see synonymies), with the exception of the Sc element. The Sc element of the Avalanche Lake species is most like *Ligonodina? variabilis* s.f. Nicoll & Rexroad, with a straight or slightly deflected anterior blade. The Sc element synonymyzed by Uyeno *in* Uyeno and Barnes (1983), and figured by Aldridge (1979), is *Ligonodina petila* s.f. Nicoll & Rexroad, which has a posteriorly deflected anterior blade. Walliser (1964) did not describe a Sc element from the type level of *Oulodus? fluegeli*, so a type apparatus can not be defined. The difference in the Sc elements is possibly a regional variation.

Oulodus? fluegeli (Walliser, 1964)

Plate 1, Figures 19-26

Pa Element

1964 *Lonchodina detorta* - Walliser: p. 43, Pl. 9, Fig. 20; Pl. 30, Figs. 34-37.

Pb Element

1964 *Lonchodina fluegeli* - Walliser: P. 44, Pl. 6, Fig. 4; Pl. 32, Figs. 22-24.

M Element

1964 *Neoprioniodus planus* - Walliser: p. 51, Pl. 4, Fig. 10; Pl. 6. Fig. 3; Pl. 29, Figs. 12, 13, 15.

Sc Element

1969 *Ligonodina? variabilis* - Nicoll and Rexroad: p. 39, Pl. 4, Figs. 12-14.

Sa Element

1964 *?Roundya trichonodelloides* - Walliser: p. 72, Pl. 6, Fig. 2; Pl. 31, Figs. 22-25.

Multielement

1975 *Ozarkodina plana* (Walliser) - Sweet and Schönlaub: p. 52-53, Pl. 1, Figs. 1, 3-6 (only).

1979 *Oulodus? fluegeli* (Walliser) - Aldridge: p. 14-15, Pl. 2, Figs. 6-11.

1982 *Oulodus? fluegeli* (Walliser) - Aldridge and Mohamed: Pl. II, Figs. 26, 27.

Diagnosis

The elements of the apparatus of *O? fluegeli* are characterized by a narrow blade with laterally compressed, closely spaced denticles and a narrow basal cavity with a slight expansion under the cusp. The Pa element is diagnostic, consisting of a slightly bowed, slightly arched anterior blade having four to five denticles and a cusp. The posterior blade deflects outward aproximately 90° to the anterior blade. The posterior blade is longer, with a pronounced twist in the blade, having nine to twelve denticles. The basal cavity is expanded under the cusp, greater inward, the flair forming an undenticulated protuberance.

Description

The elements assigned to *Oulodus? fluegeli* have been described in the literature. Aldridge (1972, 1979) gave complete descriptions of the Pa, Pb, M, Sb, and Sa elements; Nicoll and Rexroad (1969) described the Sc element characteristic of the Avalanche Lake *O? fluegeli*.

Remarks

Oulodus? fluegeli resembles the apparatus described by Aldridge (1979), with the exception of the Sc element. The Avalanche Lake Sc element is identical to the Sc element figured by Sweet and Schönlaub (1975) as *Ozarkodina plana*. Aldridge (1979) identified *O. plana* [with the exception of the Pa (Pb in Aldridge, 1979 and Sweet and Schönlaub, 1975) and Sc element] as *O? fluegeli*. A Sc element similar to the one associated with *O? fluegeli* was assigned to *Ozarkodina pirata* by Uyeno *in* Uyeno and Barnes (1983); *Oulodus? fluegeli* also occurs in the same collection.

A number of transition elements were recognized in the apparatus of *O? fluegeli*. These specimens correspond in appearance to positions between Pa-Sa, Sc-Sb, and Sb-Sa. The Sa elements are characterized by a short third blade, typically branching from under the cusp, and excessive twisting and deflection of the blades, unlike the typical form elements. The Sb element illustrated by Aldridge and Mohamed (1982) appears to be

a transition form, possibly a Sb-Sa.

Oulodus? fluegeli is the oldest species in the *O? fluegeli* group (Fig. 11). *Oulodus?* n. sp. 1 and *Oulodus?* n. sp. 2 are younger descendants. The main difference between *O? fluegeli* and *O?* n. sp. 1 is in the Pa element, which is lonchodiniform in *O? fluegeli* and diadelognathiform in *O?* n. sp 1. *Oulodus?* n. sp. 2 has a lonchodiniform Pa element, and differs from *O? fluegeli* in the greater number of denticles on the Pa, Pb, M, and Sc elements. The M element is typical of the difference. While the M element of *O? fluegeli* has five to six large denticles, the corresponding element in *O?* n. sp. 2 has nine to eleven large denticles. The other elements show a similar relationship. Elements of *O?* n. sp. 1 are intermediate in the number of denticles between *O? fluegeli* and *O?* n. sp. 2 (Fig. 11).

Range

At Avalanche Lake *Oulodus? fluegeli* ranges from the *discreta/kentuckyensis/nathani* Zone, through the *celloni* Zone, and into the lower *amorphognathoides* Zone.

Material studied

54 Pa, 55 Pb, 98 M, 109 Sc, 32 Sb, 50 Sa, 16 Transition elements.

Oulodus? n. sp. 1

Plate 4, Figures 13-19

Pa Element

1969 *Diadelognathus* sp. - Nicoll and Rexroad: p. 29-31, Pl. 6, Figs. 1-10.

Muiltielement

1983 *Oulodus? fluegeli* subsp. A - Uyeno *in* Uyeno and Barnes: p. 18-19, Pl. 7, Figs. 11-20, 22(?).

1983 *Oulodus? fluegeli* (Walliser) - Mabillard and Aldridge: Pl. 2, Figs. 15, 16.

Diagnosis

The apparatus is composed of six form elements, and consists of narrow bladed elements with narrow basal cavities and laterally compressed denticles. The Pa element is diagnostic, consisting of a large compressed cusp and a short, undenticulated expansion over the basal cavity. Two blades diverge from the cusp. The shorter blade curves

evenly away from the cusp, until the blade is approximately 90° to the short process. The blade has five to seven upright denticles. The longer blade diverges perpendicular to the short process, twisting inward, then outward in a sinuous curve. The long blade has eight to nine denticles, not as closely spaced as on the shorter blade. The basal cavity is wide under the cusp, extending under the short process and blades. The rest of the elements in the apparatus are similar to those of *Oulodus? fluegeli* and *Oulodus?* n. sp. 2.

Description

The Pa element has been described as *Diadelognathus* s.f., and the Sc element as *Lonchodina variabilis* s.f. by Nicoll and Rexroad (1969). The Pb, M, Sb, and Sa elements are similar to elements described under *Oulodus? fluegeli* in the literature. The increase in the number of denticles on the blades of the younger species and difference between the Pa elements of the *O? fluegeli* group may be used to differentiate the species (Fig. 11).

Remarks

Specimens similar or identical to *O?* n. sp 1 were assigned to *Oulodus? fluegeli* subsp. A by Uyeno *in* Uyeno and Barnes (1983). A diadelognathiform Pa element was also assigned to *O? fluegeli* by Mabillard and Aldridge (1983). The difference in the Pa element from the type of *O? fluegeli* (Walliser, 1964) and the different stratigraphic range of this form suggests that a new species be proposed. A younger species of *Oulodus?* has a detortiform Pa element similar to the type species, but the elements in the apparatus are characterized by a greater number of denticles than *O? fluegeli* or *O?* n. sp. 1. The elemental relationships and stratigraphic distribution are shown in Figure 11.

The Pa element of *O?* n. sp 1 was first described by Nicoll and Rexroad (1969), who recognized five species of *Diadelognathus* s.f. Nicoll and Rexroad (1969) believed a phylogenetic relationship existed between the five species. The species are grouped together in the synonymy because of the fragmentary nature of the type specimens and the questionable assignment of the Avalanche Lake specimens to one of these species.

The remainder of the elements are similar to the elements of *O? fluegeli* and *O?* n. sp. 2. The M element of *O?* n. sp. 1 has eight to nine denticles following the cusp, between the number on the corresponding elements of *O? fluegeli* and those of *O?* n. sp. 1. The Sc element, as discussed previously, has a straight anterior blade, unlike the Sc

element assigned to *O? fluegeli* subsp. A by Uyeno *in* Uyeno and Barnes (1983). Both the M and Sc elements have a more arched posterior blade, giving the elements a "cockscomb" appearance.

Range

At Avalanche Lake *Oulodus?* n. sp. 1 first occurs at the base of the *amorphognathoides* Zone, extending to the upper part of the zone.

Material studied

34 Pa, 19 Pb, 53 M, 39 Sc, 15 Sb, 21 Sa.

Oulodus? n. sp. 2

Plate 5, Figures 9-16

Pa element

1968 Genus and species indet. A - Igo and Koike: p. 20, Pl. I, Fig. 23.

Pb element

1968 *Plectospathodus* sp. A - Igo and Koike: p. 16, Pl. I, Figs. 13, 16, 19, 22.

Sc element

1968 *Ligonodina* sp. - Igo and Koike: p. 27, Pl. I, Fig. 27.

Transition elements

Pa-Sa

1968 *Roundya* sp. B - Igo and Koike: p. 17, Pl. I, Fig. 1, 2.

Sb-Sa

1968 *Roundya*? sp. D - Igo and Koike: p. 18. Pl. III, Fig. 29.

Diagnosis

The apparatus is composed of six form elements and transitional forms. The Pa element is diagnostic of the species within the group along with the greater number of denticles on the blade-like processes. The Pa element is lonchodiniform, consisting of an unarched, slightly bowed short blade, cusp, and long twisted blade. The long (posterior) blade is outwardly deflected at 90° to the short blade, twisted into an "S". The short blade has six denticles, closely spaced and upright. The longer blade has fourteen denticles, shorter and not as closely spaced as the denticles on the short blade.

Description

All of the elements, with the exception of the Sc element, conform to the description of *Oulodus? fluegeli* (Aldridge, 1979) in regard to the shape and character of the cusp and blades. The complete apparatus, as well as the transition elements, were described and figured by Igo and Koike (1968).

Sc element: hindeodelliform, consisting of a long process with the cusp anterior to center. The anterior blade is narrow, unarched, slightly to moderately bowed, with five to seven denticles. The denticles are long, elliptical in cross-section, with discrete bases, slightly curved posteriorly. The cusp is posteriorly reclined, and longer than the denticles. The posterior blade is long, inwardly curved and twisted. The denticles are more posteriorly reclined and more widely spaced than the anterior denticles, elliptical, and nine to eleven in number. The basal cavity is only slightly expanded, if at all, under the cusp.

Remarks

Oulodus? n. sp. 2 is a late form of the *O? fluegeli* group, younger than the species described by Aldridge (1979), which was associated with a *celloni* Zone fauna. Form elements described by Igo and Koike (1968) from Malaysia, that correspond to the elements of *O?* n. sp. 2, were associated with *P. amorphognathoides*. *Oulodus?* n. sp. 2 differs from *O?* n. sp. 1 in the nature of the Pa element, but the corresponding element in *O? fluegeli* is similar (Fig. 11). Transition elements assigned to *O?* n. sp. 2 are similar to transition forms associated with *O? fluegeli*, indicating a close relationship. No transitional elements were associated with *O?* n. sp. 1, indicating a separate branch from the *O? fluegeli* - *O?* n. sp. 2 lineage, also supported by the different Pa elements (Fig. 11). The transition elements correspond to positions between Pa-Sa, Sc-Sb, and Sb-Sa.

Range

Oulodus? n. sp. 2 occurs in the upper *amorphognathoides* Zone at Avalanche Lake.

Material studied

20 Pa, 17 Pb, 27 M, 22 Sc, 11 Sb, 5 Sa, 23 Transition elements.

Oulodus? kentuckyensis (Branson & Branson, 1947)

Plate 1, Figures 16, 17

Pa Element

1967 *Lonchodina* sp. - Rexroad: p. 38, Pl. 3, Fig. 5.

Pb Element

1957 *Lonchodina* n. sp. b - Walliser: p. 40, Pl. 3, Figs. 27, 28.

M Element

1967 *Euprioniodina* cf. *Prioniodus excavatus* Branson & Mehl - Rexroad: p. 31-32, Pl. 3, Figs. 7, 8.

Sc Element

1947 *Ligonodina kentuckyensis* - Branson and Branson: p. 555, Pl. 82, Figs. 28, 35.

Sb Element

1947 *Prioniodina irregularis* - Branson and Branson: p. 555, Pl. 82, Figs. 30, 31.

Sa Element

1967 *Trichonodella* n. sp. A - Rexroad: p. 52-53, Pl. 3, Figs. 16, 18.

Multielement

1975 c.f. *Oulodus* n. sp. A - Cooper: p. 997, Pl. 2, Figs. 16, 18, 19, 21 (only).

1975 c.f. *Oulodus* n. sp. B - Cooper: p. 997-998, Pl. 2, Figs. 15, 17, 20 (only).

1981 *Oulodus? kentuckyensis* (Branson & Branson) - McCracken and Barnes: p. 80-81, Pl. 6, Figs. 1-20.

1981 *Oulodus? kentuckyensis* (Branson & Branson) - Fåhraeus and Barnes: Pl. 1, Figs. 5, 6.

1981 *Oulodus? kentuckyensis* (Branson & Branson) - Nowlan: Pl. 4, Figs. 15, 19.

1982 *Oulodus kentuckyensis* (Branson & Branson) - Aldridge and Mohamed: Pl. I, Figs. 29-32.

1982 *Oulodus? kentuckyensis* (Branson & Branson) - McCracken and Barnes: p. 1481-1482, Pl. 2, Fig. 14.

Diagnosis

The apparatus is composed of six form elements. Elements are robust, denticles ovoid to circular and peg-like, with wide U-shaped interspaces. The Pa element differs from the other elements in the apparatus in having more compressed and closely spaced denticles on the anterior blade. The Sc element is distinctive in the aboral deflection of the anterior blade at 90° to the posterior blade.

Description

Elements assigned to *O? kentuckyensis* have been described in form and multielement taxonomy; a complete description was given in McCracken and Barnes (1981). M elements from Avalanche Lake differ from the type specimen and the figured specimens of McCracken and Barnes (1981) in that the anterior process is extremely short and rounded, typically with only a single denticle.

Remarks

Following the discussion of *O? kentuckyensis* by McCracken and Barnes (1981), the species of Cooper (1975), *O?* sp. A and *O?* sp. B (in part) are included with *O? kentuckyensis*. A lineage possibly descended from *O? kentuckyensis* occurs in the *celloni* and *amorphognathoides* zones. These species of *Oulodus?* are characterized by Pa elements with oulodiform and laterally compressed denticles, and Sc elements with aborally and posteriorly deflected anterior processes. The trend is for the younger species to have less twisted Pa elements and longer anterior processes deflected more posteriorly on the Sc element (Fig. 12).

Range

Oulodus? kentuckyensis was recognized from only a single horizon at Avalanche Lake in the lower *discreta/kentuckyensis/nathani* Zone.

Material studied

3 Pa, 4 Pb, 2 M, 20 Sc, 3 Sb, 5 Sa.

Oulodus? nathani McCracken & Barnes, 1981

Plate 1, Figure 15

Multielement

1981 *Oulodus? nathani* - McCracken and Barnes: p. 81-82, Pl. 6, Figs. 21-32.

1981 *Oulodus? nathani* McCracken & Barnes - Nowlan: Pl. 4, Figs. 14, 17.

Diagnosis

Multielement *O? nathani* is characterized by elements with a slender cusp and denticles. The denticles are compressed and closely spaced, unlike typical oulodiform denticles. The basal cavity is generally small. The Pa element is characteristic, diagnosed by McCracken and Barnes (1981).

Description

Oulodus? nathani was described by McCracken and Barnes (1981).

Remarks

The complete apparatus of *O? nathani* could not be reconstructed from the Avalanche Lake collections. Identification of the species was based on a single Pa element. Other *Oulodus?* elements occur in the sample with the Pa element, but could not be confidently assigned to *O? nathani*.

Range

Oulodus? nathani was used to define the lowest Silurian conodont zone in eastern Canada by McCracken and Barnes (1981), though the species has not been found to extend down to the Ordovician-Silurian boundary (Nowlan, 1983; McCracken, pers. comm., 1983). At Avalanche Lake the specimen is placed in the *discreta/kentuckyensis/nathani* Zone which extends from the first occurrence of *D. kentuckyensis*.

Material studied

1 Pa.

Oulodus? n. sp. C

Plate 4, Figures 20-24, 28, 29

Diagnosis

An apparatus of Pa (oulodiform), Pb (eoligonodiniform?), M (prioniodiniform), Sc (ligonodiniform), Sb (zygognathiform), and Sa (hibbardelliform) elements. The elements are robust with oval, peg-like denticles, with wide, U-shaped interspaces. The basal cavity is shallow, flared under the cusp.

Description

Pa element: oulodiform, consisting of a central cusp and "S" shaped processes with oulodiform denticles on the posterior blade, and more compressed, closely spaced denticles on the anterior blade. The cusp is long, with a round cross-section, posteriorly and inwardly reclined. The anterior blade is outwardly twisted, curving away from the cusp, with six to seven denticles. The posterior blade is inwardly curved and slightly twisted, with six denticles. The basal cavity is widely expanded, narrowing toward the ends of the blades.

Pb element: only partial elements were found, consisting of a wide based cusp and a strongly curved anterior blade. The cusp is posteriorly reclined and circular in cross-section. The anterior process is narrow, curved 90° to the cusp, with small, oulodiform denticles. The basal cavity is expanded under the cusp.

M element: euprioniodiniform, consisting of a cusp with short and long processes. The cusp is round in cross-section, posteriorly curved, with a rounded, basal, posterior protuberance. The short process narrows rapidly away from the cusp, curving downward and outward, with none to two small denticles. The longer process is deflected downward from the cusp, with five to six denticles, widely spaced, becoming smaller away from the cusp. The basal cavity is narrow, expanded under the cusp and posterior protuberance.

Sc element: ligonodiniform, consisting of a posteriorly curved cusp, short anterior process and long posterior process. The anterior process tapers away from the cusp, and is laterally and aborally deflected with four widely spaced oulodiform denticles. The posterior process is long with posteriorly reclined denticles, the larger denticles in the middle of the process.

Sb element: zygognathiform, consisting of a large cusp and short and long processes. The cusp is posteriorly reclined with a broad basal protuberance on the posterior side. The short process narrows away from the cusp, with four oulodiform denticles. The longer process is typically broken, aborally deflected and curved with oulodiform denticles. The basal cavity is widely expanded under the cusp.

Sa element: hibbardelliform with a long posterior bar. The cusp is posteriorly curved, ovoid in cross-section. The lateral processes are aborally deflected with a posterior curve, each with three large denticles and a smaller denticle on the end of the process. The posterior bar is long, with at least six long posteriorly reclined, widely spaced denticles.

Remarks

Oulodus? n. sp. C resembles *O? kentuckyensis* in general form of the Pa element and aboral deflection of the anterior process on the Sc element. Both species are characterized by robust elements, *O?* n. sp C possibly evolving from *O? kentuckyensis*. A phylogenetic relationship can not be supported because of the lack of species range

overlap or intermediate specimens.

Range

At Avalanche Lake *Oulodus?* n. sp. C first appears in the base of the *celloni* Zone, following a thick chert unit (Member 2W), extending into the lower *amorphognathoides* Zone.

Material studied

4 Pa, 5 Pb, 2 M, 8 Sc, 5 Sb, 6 Sa.

Oulodus? n. sp. D

Plate 5, Figures 17-19, 23

Diagnosis

The assemblage is only partially reconstructed, elements in the Pa, Pb, Sc, and Sa positions assigned. The Pa element is oulodiform, consisting of a long, narrow blade, laterally twisted and posteriorly arched. Denticles on the blade are discrete, but closely spaced.

Description

Pa element: modified oulodiform, with a small medial cusp. The anterior half of the blade is unarched, slightly bowed, with six, discrete, closely spaced, laterally compressed, erect denticles. The posterior half is arched and twisted, laterally deflected behind the cusp, then bending aborally and twisted across the longitudinal axis. The posterior blade has seven large denticles, slightly compressed and not as closely spaced as the denticles on the anterior blade. The basal cavity is expanded under the cusp, narrow under the blades.

Pb element: lonchodiniform, with a central cusp over an expanded basal cavity and two processes. The longer anterior process is slightly bowed, with four large, peg-like denticles and a small denticle close to the cusp. The posterior process is deflected at a high angle to the anterior process, with four oulodiform denticles. The basal cavity is expanded under the cusp and all but the distal portions of the processes.

Sc element: ligonodiniform, characterized by a long aborally and posteriorly deflected anterior process. The cusp and posterior process are aligned, the blade with five to six large, slightly reclined, oulodiform denticles. The anterior process has six

denticles, which are small in size.

Sa element: trichonodelliform, with a posteriorly curved cusp and posteriorly deflected lateral processes. The processes have five oulodiform denticles.

Remarks

Only a partial reconstruction was possible from the collection. The Pa element resembles the corresponding element of *O? kentuckyensis*, both species having long unarched blades. The Pa element of *Oulodus?* n. sp. C is also similar. The Sc elements of the three species are characterized by a posterior-aboral deflection of the anterior blade, indicating a close species relationship (Fig. 12).

Range

At Avalanche Lake *Oulodus?* n. sp. D occurs in the upper *amorphognathoides* Zone.

Material studied

3 Pa, 1 Pb?, 13 Sc, 2 Sa.

Oulodus? n. sp. F

Plate 6, Figures 14-17, 21, 22

Diagnosis

A complete apparatus was reconstructed, consisting of elements assigned to the Pa, Pb, M, Sc, Sb, and Sa positions. The elements are characterized by discrete, widely spaced, peg-like denticles, the denticles appearing undersized relative to the blades. Most of the specimens still have part of the basal plate present along the basal margin.

Description

Pa element: modified oulodiform, consisting of a low blade which is slightly bowed. The anterior blade has six widely spaced oulodiform denticles. The posterior blade is slightly twisted, with six to eight denticles, round in cross-section, closely spaced, and larger posteriorly. The basal cavity is wide under the entire element, expanded below the cusp with lateral flares.

Pb element: lonchodiniform, consisting of a highly arched blade. The anterior process is aborally deflected and slightly bowed, with four to five denticles, longer toward the cusp. The cusp is large, posteriorly reclined and slightly twisted. The

posterior process is shorter than the anterior process, with three to four denticles. A narrow basal groove extends the length of the element, widening under the cusp.

M element: prioniodiform, consisting of a compressed cusp and two processes. The anterior process is short, with two small denticles. The posterior process arches aborally and narrows posteriorly with uniform denticles. The basal cavity is flared under the cusp and narrows posteriorly.

Sc element: ligonodiniform, consisting of a posteriorly deflected anterior process, a cusp, and a long posterior process. The cusp is posteriorly reclined. The anterior process is laterally and aborally deflected from the cusp. The posterior process is straight and slightly arched with at least eight, widely spaced reclined denticles. The basal cavity is flared on the outside margin below the cusp.

Sb element: zygognathiform, composed of a robust blade with a central cusp. Processes are slightly twisted, with three to four robust, widely spaced denticles. The last denticle of the process is commonly on the end, giving the element a hooked appearance.

Sa element: trichonodelliform, consisting of a large, posteriorly reclined cusp, and two lateral processes. The processes are deflected aborally, with a slight posterior curvature. Denticles are oulodiform, four on each process, becoming closer spaced toward the cusp. The basal cavity is expanded posteriorly under the cusp.

Remarks

The Pa element of *O?* n. sp. F is similar to the the corresponding element of *O?* n. sp. D. Both of the species have laterally compressed anterior denticles and oulodiform denticles on the posterior blade. The younger species has a greater basal expansion and reduced twisting of the posterior process. The Sc elements differ in the smaller number of denticles and greater posterior deflection of the anterior process in *O?* n. sp. F.

Range

Oulodus? n. sp. F occurs in the *patula/ranuliformis* Zone at Avalanche Lake.

Material studied

7 Pa, 6 Pb, 3 M, 7 Sc, 6 Sb, 6 Sa.

Oulodus? n. sp. I

Plate 7, Figures 14, 17, 20

Diagnosis

The apparatus is only partially reconstructed. The Pa? element is a modified blade uncharacteristic of *Oulodus*, composed of a narrow arched process. Denticles are long, closely spaced, basally fused, and laterally compressed. The Sc element is ligonodiniform, and has an extremely long anterior process with numerous denticles. The anterior process is deflected posteriorly and aborally, extending well behind the cusp.

Description

Pa? element: moderately arched and bowed blade, with a central cusp. The cusp is laterally compressed, basally fused to the nearest anterior denticle. The anterior blade is slightly arched, low at the anterior end, high toward the cusp. The denticles, six, becoming longer and larger toward the cusp, are basally fused and laterally compressed. The posterior blade is lower than the anterior blade, more arched and twisted, with six oulodiform denticles, subequal in size and basally fused. The basal cavity is widely expanded, elliptical in shape, narrowing under the processes.

Pb element: lonchodiniform, strongly arched and slightly bowed, element consisting of a large cusp and robust lateral processes, subequal in length. The longer process has four to five oulodiform denticles with wide U-shaped interspaces. The shorter process has three to four denticles. The basal cavity is expanded under the cusp, narrowing under the processes.

Sc element: ligonodiniform, consisting of a large cusp, well denticulated posterior process, and long anterior process. The posterior process is straight, with up to eleven reclined denticles, circular in cross-section, and widely spaced. The anterior process is long, posteriorly and aborally deflected, with nine oulodiform denticles. The basal plate is commonly still in place under the cusp, obscuring the basal cavity.

Remarks

The nature of the Pa? element and Sc element suggests that *O?* n. sp. I is related to *O?* n. sp. D and/or *O?* n. sp. F. All of these species have Pa elements with oulodiform denticles on the posterior blade and laterally compressed denticles on the anterior blade. The trend is for process base to broaden and the blade straighten (Fig. 12). If the blade element *Oulodus?* species from Avalanche Lake are all related, the lineage is of

biostratigraphic value. The limited number of specimens and their exclusive ranges prevents direct correlation, though a lineage is possible (Fig. 12).

Range

Oulodus? n. sp. I occurs in the *bohemica* Zone at Avalanche Lake.

Material studied

2 Pa?, 5 Pb, 9 Sc.

SUPERFAMILY POLYGNATHACEA Bassler, 1925

4.7 Family Kockelellidae Klapper, 1981

4.7.1 Genus *Kockelella* Walliser, 1957

Type Species

1957 *Kockelella variabilis* - Walliser: p. 35-36, Pl. 1, Figs. 3-10.

Remarks

Multielement apparatus *Kockelella* is composed of six distinct skeletal elements (Barrick and Klapper, 1976): Pa, Pb, M, Sc, Sb, and Sa. The Pa element is spathognathodiform; Pb is ozarkodiniform; M is neoprioniodiform; Sc is ligonodiniform; Sb is lonchodiniform; Sa is trichonodelliform. The Pa elements are characteristically modified in the posterior half of the blade, either with an expanded basal cavity, and/or one or more lateral processes.

Kockelella absidata Barrick & Klapper, 1976

Plate 6, Figures 3, 4, 6, 7

Pa Element

1957 *Spathognathodus* cf. *primus* (Branson & Mehl) - Walliser: p. 48, Pl. 1, Figs. 1, 2.

Multielement

1976 *Kockelella absidata* - Barrick and Klapper: p. 73-74, Pl. 2, Figs. 15, 16.

Diagnosis

The Pa element is characterized by a slightly bowed anterior blade with long, erect denticles. The cusp is strongly reclined. The posterior blade is deflected outward, and is

much lower than the anterior blade, totally underlain by the basal cavity. The basal cavity is unequally expanded, extending under the cusp, and to the tip of the posterior blade and posterior process.

Description

The elements assigned to *K. absidata* were described by Barrick and Klapper (1976).

Remarks

Only part of the apparatus was reconstructed from Avalanche Lake. The Pa elements assigned to *K. absidata* are similar to the elements figured by Barrick and Klapper (1976), where the basal expansion extends to the posterior end of the element. Another form, *"Ozarkodina" fundamentata* Walliser has been synonymyzed with *K. absidata*. The basal cavity in *"O." fundamentata* only extends under two to three denticles, not reaching the end of the element (Walliser, 1964; Barrick and Klapper, 1976).

The M element of *K. absidata* is identical to the corresponding element in *Kockelella variabilis* (Walliser). The M elements from Avalanche Lake are identical to the M element assigned to *K. variabilis* figured by Uyeno (1981). These elements differ in appearance from the holotype, *Neoprioniodus multiformis* s.f. (Walliser, 1964), although they are similar to two specimens illustrated by Walliser (1964) (Pl. 29, Figs. 21, 22). The M element of *Kockelella amsdeni* (identical to M element of *K. variabilis*) illustrated by Barrick and Klapper (1976) is also different, having a much narrower cusp and longer process. The difference in M elements may be the result of local variation. The M element figured by Uyeno (1981) was from the Canadian Arctic Islands.

Kockelella absidata is phylogenetically related to *Kockelella ranuliformis* (Barrick and Klapper, 1976). *Kockelella absidata* first occurs in the Clarita Fm., Oklahoma, in the *amsdeni* Zone, after the extinction of *K. walliseri*. At Avalanche Lake *K. absidata* appears in the upper *patula/ranuliformis* Zone, below the only occurrence of *K. walliseri*. The range of *K. absidata* is similar to that recorded for the species in the Clarita Limestone (Barrick and Klapper, 1976).

Range

At Avalanche Lake *Kockelella absidata* first occurs in the upper *patula/ranuliformis* Zone, extending into the *bohemica* Zone.

Material studied

2 Pa, 2 Pb, 3 M.

Kockelella patula Walliser, 1964

Plate 6, Figure 2

Pa Element

1964 *Kockelella patula* - Walliser: p. 39-40, Pl. 7, Fig. 2; Pl. 15, Figs. 16-25.

Pb Element

1964 *Ozarkodina ziegleri aequalis* - Walliser: p. 62, Pl. 7, Fig. 1; Pl. 24, Figs. 19-21, Text-Fig. 3 f.

M Element

1964 *Neoprioniodus multiformis* - Walliser: p. 50-51, Pl. 8, Fig. 10; Pl. 29, Fig. 16.

Multielement

1964 Conodonten-Apparat E - Walliser: p. 17-18.

1972 *Kockelella patula* Walliser - Walliser: p. 77.

1976 *Kockelella patula* Walliser - Barrick and Klapper: p. 75, Pl. 3, Fig. 18-26.

Diagnosis

The Pa element has three or more lateral processes extending from the posterior half of the element and a short posterior process. The blade has short, tightly packed denticles; the lateral processes have irregular denticles or nodes. The basal cavity is widely expanded under the posterior and lateral processes.

Description

Elements assigned to *K. patula* have been described in form element terminology Walliser (1964).

Remarks

Only the Pa element was recognized in the collection. The specimens are similar to the holotype and the specimens illustrated by Barrick and Klapper (1976). *Kockelella patula* was only found in two samples, both from Member 2D. The oldest sample is probably not the oldest occurrence, as the sample horizon is just above a thick shale unit (Member 1D) which yielded few conodonts. Near the base, or within this shale sequence, the *Pterospathodus* extinction plane occurs. *Kockelella patula* first appears just after the

extinction of *P. amorphognathoides* at the Cellon section (Walliser, 1964), though there are probably unconformities in the sequence (Schönlaub, 1971). *Kockelella patula* occurs in the *amsdeni* Zone in Oklahoma (Barrick and Klapper, 1976).

Range

Established conodont zone index species, *K. patula* and *K. ranuliformis* characterise the *patula/ranuliformis* Zone in the Avalanche Lake area. The base of the zone defined by the first occurrence of *K. ranuliformis*. At Avalanche Lake, *K. patula* occurs within the *patula/ranuliformis* Zone.

Material studied

5 Pa.

Kockelella ranuliformis (Walliser, 1964)

Plate 6, Figure 1

Pa element

1964 *Spathognathodus ranuliformis* - Walliser: p. 82, Pl. 6, Fig. 9; Pl. 22, Figs. 5-7.

Multielement

1975 *Ozarkodina? ranuliformis* (Walliser) - Schönlaub: p. 57, Pl. 1, Figs. 5, 7.

1976 *Kockelella ranuliformis* (Walliser) - Barrick and Klapper: p. 76, Pl. 2, Figs. 1-11.

1983 *Kockelella ranuliformis* (Walliser) - Uyeno *in* Uyeno and Barnes: p. 18, Pl. 6, Fig. 1-4.

Diagnosis

The Pa element is composed of a slightly bowed, unarched blade with an expanded, round basal cavity under the posterior half. The basal cavity extends to the end of the element. There are no lateral processes. Denticles on the blade are short and laterally compressed.

Description

Elements assigned to *K. ranuliformis* have been described by Barrick and Klapper (1976).

Remarks

Only two complete Pa elements were recovered in the Avalanche Lake collection. The specimens are from the top of Member 3W, concurrent with, or after, the last

occurrence of *P. amorphognathoides*. The first occurrence of *K. ranuliformis* defines the base of the *patula/ranuliformis* Zone.

Range

At Avalanche Lake *K. ranuliformis* occurs in the lowermost part of the *patula/ranuliformis* Zone, coincident with the extinction of *P. amorphognathoides*.

Material studied

2 Pa.

Kockelella walliseri (Helfrich, 1975)

Plate 6, Figure 5

Pa Element

1964 *Spathognathodus* n. sp. - Walliser: p. 88, Pl. 22, Fig. 8.

1975 *Kockelella walliseri* - Helfrich: Pl. 1, Figs. 1, 9, 10, 19, 21.

Diagnosis

The Pa element is the only element of the apparatus recognized. The Pa is characterized by a slightly anteriorly deflected posterior lateral process. The basal cavity is widely expanded, extending to the end of the element and end of the lateral process, giving an ovoid outline to the basal expansion in the oral view.

Description

A complete description of the Pa element was given by Barrick and Klapper (1976). The remainder of the apparatus is probably similar to that of *K. ranuliformis* (see Barrick and Klapper, 1976).

Remarks

Only one poorly preserved Pa element was recognized in the Avalanche Lake collection. The specimen occurs after tha last occurrence of *K. patula* and *K. absidata*. In the Clarita Formation, Oklahoma, the range of *K. walliseri* ends before the first occurrence of *K. patula* or *K. absidata*. At Avalanche Lake *K. walliseri* occurs in association with *O. bohemica*, similar to the range recorded in the eastern United States (Helfrich, 1975). *Kockelella walliseri* was found in association with *P. amorphognathoides* from a section in the Root Basin (62° 48' N, 125° 15' W). The species was abundant, and indicates a lower range for *K. walliseri* in the Mackenzie

Mountains, similar to that recorded in Oklahoma.

Range

Kockelella walliseri occurs in the *bohemica* Zone at Avalanche Lake, but is found in older strata with *P. amorphognathoides* in the Root Basin.

Material studied

1 Pa.

4.8 Family Polygnathidae Bassler, 1925

4.8.1 Genus *Ozarkodina* Branson & Mehl, 1933

Type Species

1933 *Ozarkodina typica* - Branson and Mehl: p. 51-52, Pl. 3, Figs. 43-45. [= junior synonym of *Ozarkodina confluens* (Branson & Mehl)]

Remarks

Multielement *Ozarkodina* is composed of six distinct skeletal form elements (Klapper and Phillip, 1971): Pa, Pb, M, Sc, Sb, and Sa. The Pa element is spathognathodiform; Pb is ozarkodiniform; M is neoprioniodiform or synprioniodiform; Sc is hindeodelliform; Sb is plectospathodiform; Sa is trichonodelliform.

Ozarkodina bohemica (Walliser, 1964)

Plate 7, Figure 8

Pa Element

1964 *Spathognathodus sagitta bohemicus* - Walliser: p. 83, Pl. 7, Fig. 4; Pl. 18, Figs. 23, 24.

Pb Element

1964 *Ozarkodina edithae* - Walliser: p. 55-56, Pl. 26, Figs. 15, 16.

Multielement

1975 *Ozarkodina sagitta bohemica* (Walliser) - Aldridge: Pl. 2, Figs. 18, 19.

1976 *Ozarkodina sagitta bohemica* (Walliser) - Barrick and Klapper: p. 81, Pl. 4, Fig. 1-7, 10-12.

Diagnosis

Multielement *Ozarkodina bohemica* was reconstructed by Barrick and Klapper (1976), consisting of six form elements. The Pa element is diagnostic, having a characteristic fusion of denticles above the basal cavity. The basal cavity is widely expanded, the inner flare larger and more squarish compared to the nearly circular outer flare, tapering toward the posterior end of the element.

Description

Elements assigned to *O. bohemica* have been described in the literature. The Pa and Pb elements were described in form taxonomy by Walliser (1964), Barrick and Klapper (1976) reviewed the species and discussed its relationship to other species.

Remarks

Ozarkodina bohemica is considered a separate species from *Ozarkodina sagitta* (Klapper *in* Ziegler (ed), 1977). The original diagnosis of *O. bohemica*, in a multielement assemblage, was as a subspecies of *O. sagitta*. Elements of the two species are quite similar. The Pa elements distinguish the species, but in contrast, the Pb elements are indistinguishable. Because of the fragmentary nature of the specimens in the samples, the M and S transition elements are only questionably assigned to *O. bohemica*.

Range

The first appearance of *O. bohemica* defines the base of the *bohemica* Zone, the youngest Silurian conodont zone recognized in the Avalanche Lake sections. *Ozarkodina bohemica* extends into Ludlow strata in Europe and the eastern United States, but the Wenlock-Ludlow boundary can not be defined at present in the Avalanche Lake sections to determine the extent of its range.

Matderial studied

24 Pa, 6 Pb, 5 M?, 4 Sc?, 2 Sb?.

Ozarkodina confluens (Branson & Mehl, 1933)

Plate 7, Figures 9-13

Pa Element

1933 *Spathodus primus* - Branson and Mehl: p. 46, Pl. 3, Figs. 25-30.

Pb Element

1933 *Ozarkodina typica* - Branson and Mehl: p. 51-52, Pl. 3, Figs. 43-45.

M Element

1933 *Prioniodus bicurvatus* - Branson and Mehl: p. 44, Pl. 3, Figs. 9-12.

Sc Element

1933 *Hindeodella confluens* - Branson and Mehl: p. 45, Pl. 3, Figs. 21-33.

Sb Element

1933 *Plectospathodus flexuosus* - Branson and Mehl: p. 47, Pl. 3, Figs. 31, 32.

Sa Element

1933 *Trichognathus symmetrica* - Branson and Mehl: p. 50, Pl. 3, Figs. 33, 34.

Multielement

1969 *Hindeodella confluens* Branson & Mehl - Jeppsson: p. 15-18, Text-Fig. 1 A-F; Text-Fig. 2.

1975 *Ozarkodina confluens* (Branson & Mehl) - Aldridge: Pl. 2, Figs. 1-6.

1975 *Ozarkodina confluens* (Branson & Mehl) - Klapper and Murphy: p. 30-33, Pl. 3, Figs. 1-23; Pl. 4, Figs. 1-27; Pl. 8, Figs. 11-15.

1977a *Ozarkodina confluens* (Branson & Mehl) - Cooper: p. 187-188, Pl. 16, Figs. 1-7.

1978 *Ozarkodina confluens* (Branson & Mehl) - Rexroad, *et al.*: p. 7, Pl. 1, Figs. 11-16.

1980 *Ozarkodina confluens* (Branson & Mehl) - Mayr, *et al.*: Pl. 32.1, Figs. 15, 16, 22-25, 36, 41, 42.

1981 *Ozarkodina confluens* (Branson & Mehl) - Uyeno: p. 40, Pl. 1, Figs. 1-34.

1981 *Ozarkodina confluens* (Branson & Mehl) - Nowlan: Pl. 7, Figs. 18, 19, 22-24.

Diagnosis

Ozarkodina confluens was reconstructed by Jeppsson (1969), consisting of six skeletal form elements. The Pa element is diagnostic, a single blade element with a high anterior third, the blade tapering posteriorly. Denticles are short, basally fused, laterally compressed, erect or posteriorly reclined. The basal cavity is expanded in a small area near the midlength of the blade. A great degree of variation occurs in the morphology of the Pa element.

Description

Elements assigned to *O. confluens* have been described by Walliser (1964) and by Klapper and Murphy (1975). Klapper and Murphy (1975) recognized and described five

morphotypes of the Pa element.

Remarks

Four of the five morphotypes of the Pa element described by Klapper and Murphy (1975) are recognized in the Avalanche Lake collection: alpha, beta, gamma, and epsilon morphotypes. Not all of the Pa elements assigned to *O. confluens* can be assigned with confidence to these morphotypes because of the considerable variation within the species. Two variations of the gamma morphotype are notable. A number of specimens have four to five small denticles on the front of the blade, climbing from the base of the blade to the first large denticle. This form is similar to a specimen illustrated by Klapper and Murphy (1975), though the later form lacks the small anterior denticles (Klapper and Murphy, 1975, Pl. 3, Fig. 1). A second gamma morphotype variation has an expanded triangular shaped basal cavity. In these specimens the anterior portion of the basal cavity is expanded at approximately the midlength of the blade. The flare then tapers, triangular in outline, toward the posterior end of the blade.

The form assigned epsilon morphotype? by Klapper and Murphy (1975) was also recognized in the Avalanche Lake collection. This form occurs in association with epsilon morphotype elements in the youngest Avalanche Lake sample (AV 7 430 m).

Elements assigned to *O. confluens* in the Avalanche Lake collection are commonly fragmentary, accounting for the sample bias of the more robust and easily identifiable Pa and Pb elements. The M and S elements assigned to *O. confluens* are most like the specimens figured by Rexroad, *et al.* (1978) from Indiana, and Nowlan (1981) from Québec. In these specimens, the denticles are not as closely spaced or fused as the specimens figured by Klapper and Murphy (1975) and Aldridge (1975).

Rexroad *et al.* (1978) described a new subspecies of *O. confluens* (unnamed), based on the Pb element, which differs from the type species. It is probable that the Pb element, noting the variability of the Pa element, is also quite variable. In addition to the typical form of the Pb element, a number of specimens have a large denticle on the anterior blade which is nearly the size of the cusp. The specimens assigned to Gen. sp. Indet. E in this study may represent a Pb element in the *O. confluens* apparatus, most likely corresponding with the epsilon morphotype or epsilon morphotype?. The specimens are associated with the late form of *O. confluens*, but beside a similarity in

denticle shape and element texture, they have no resemblance to the Pb element usually associated with *O. confluens confluens* or the subspecies of Rexroad, *et al.* (1978). The epsilon forms of *O. confluens* may be better separated from the species and reassigned to a new species.

Ozarkodina confluens has been recorded from strata of upper Wenlock to Pridoli age. The oldest records of *O. confluens* are from the Wenlock Shale, in upper Wenlock strata correlative with the type Wenlock section (Aldridge, 1975). Nowlan (1981) reported *O. confluens* from the La Vieille Formation, Québec, indicating an upper Wenlock age, as an overlying megafauna is indicative of Ludlow age. Both of these records are of the alpha morphotype. This suggests an upper Wenlock age for the first occurrence of *O. confluens* at Avalanche Lake. *Ozarkodina confluens* first occurs in association with *K. patula* at AV 2, and *O. bohemica* at AV 4. The lower range of *O. bohemica* is in the middle Wenlock, indicating that the first occurence of *O. confluens* may be older in the Avalanche Lake area than in other regions.

The epsilon morphotype and epsilon morphotype? do not occur until after the extinction of *Kockelella variabilis* in Nevada (Klapper and Murphy, 1975), indicating a middle Ludlow age or younger. The epsilon morphotype is indicative of a Ludlow or Pridoli age in Arctic Canada (Uyeno, T., GSC, pers. comm., 1984). The oldest recorded middle-late Ludlow age of *O. confluens* epsilon morphotype indicates a much younger age for the fauna from AV 7 430 m than the youngest recognized zone (*bohemica* Zone) at Avalanche Lake. The alpha morphotype also occurs with the epsilon form at AV 7 430 m. Because of the common occurrence of the alpha, beta and gamma morphotypes at the same stratigraphic horizon, these forms are not considered to be particularly valuable for correlation or dating, though the alpha morphotype appears to be the oldest form. The epsilon morphotype, however, first occurs in strata younger than the first appearances of any of the other morphotypes, indicative of Ludlow or Pridoli age. The similarity of *O. hadra* to the delta morphotype (Klapper and Murphy, 1975) would indicate that the delta morphotype would be the oldest form if *O. confluens* developed from *O. hadra*. Barrick and Klapper (1976) and Helfrich (1980) suggested a *gulletensis-hadra-confluens* lineage. *Ozarkodina* n. sp. I is another possible ancestor of *O. confluens* (Fig. 14).

Range

At Avalanche Lake *Ozarkodina confluens* first occurs at the base of the *bohemica* Zone, the range extending above the youngest Avalanche Lake sample, AV 7 430 m, which is Ludlow or Pridoli in age, determined from the presence of the epsilon morphotype and *P. arcticus*. **Material studied**

67 Pa, 13 Pb, 2 M, 8 Sc, 4 Sb, 1 Sa.

Ozarkodina excavata excavata (Branson & Mehl, 1933)

Plate 6, Figures 8, 9

Pa Element

1933 *Ozarkodina simplex*- Branson and Mehl: p. 52, Pl. 3, Fig. 46, 47.

Pb Element

1953 *Ozarkodina* sp. - Rhodes: p. 333, Pl. 23, Fig. 244.

M Element

1933 *Prioniodus excavatus* - Branson and Mehl: p. 45, Pl. 3, Figs. 7, 8.

Sc Element

1953 *Hindeodella equidentata* - Rhodes: p. 303, Pl. 23, Figs. 248, 252-254.

Sb Element

1953 *Plectospathodus extensus* - Rhodes: p. 323, Pl. 23, Figs. 236, 238-240.

Sa Element

1933 *Trichognathus excavata* - Branson and Mehl: p. 51, Pl. 3, Fig. 35, 36.

Multielement

1964 Conodonten-Apparat H - Walliser: p. 18-19.

1969 *Hindeodella excavata* (Branson & Mehl) - Jeppsson, p. 18-20, Text-Figs. 1 G-L; Text-Fig. 3.

1972 *Ozarkodina inclinata* (Rhodes) - Walliser: p. 78.

1972 *Hindeodella excavata* (Branson & Mehl) - Jeppsson: p. 61-62, Pl. 1, Fig. 30; Text-Fig. 1 A.

1975 *Ozarkodina excavata excavata* (Branson & Mehl) - Klapper and Murphy: p. 34-37, Pl. 6, Figs. 1-20.

1975 *Hindeodella excavata excavata* (Branson & Mehl) - Jeppsson: p. 25-31, Pl. 4, Figs. 1-17.

1975 *Ozarkodina excavata* (Branson & Mehl) - Aldridge: Pl. 2, Figs. 9-14.

1976 *Ozarkodina excavata excavata* (Branson & Mehl) - Barrick and Klapper: p. 78-79, Pl. 4, Figs. 13-23, 26.

1976 *Ozarkodina excavata* Fåhraeus (sic) - Mehrtens and Barnett: p. 497, Pl. 1, Figs. 11, 12, 14, 18, 21.

1977a *Ozarkodina excavata* (Branson & Mehl) - Cooper: p. 188, Pl. 16, Figs. 8-15.

1978 *Ozarkodina excavata* (Branson & Mehl) - Helfrich: Pl. 2, Figs. 1-7.

1978 *Ozarkodina excavata excavata* (Branson & Mehl) - Rexroad *et al.*: p. 9-10, Pl. 1, Figs. 17-22.

1980 *Ozarkodina excavata* (Branson & Mehl) - Helfrich: Pl. 2, Figs. 31-38.

1981 *Ozarkodina excavata excavata* (Branson & Mehl) - Uyeno: p. 41, Pl. 2, Figs. 6-13, 17.

1981 *Ozarkodina excavata excavata* (Branson & Mehl) - Nowlan: Pl. VI, Figs. 10-16, 18.

1982 *Ozarkodina excavata* (Branson & Mehl) - Aldridge and Mohamed: Pl. I, Figs. 16, 17.

1983 *Ozarkodina excavata* (Branson & Mehl) - Mabillard and Aldridge: Pl. 3, Figs. 1-6.

Diagnosis

Six form elements are recognized in the apparatus of *O. e. excavata*. The species is characterized by moderately arched and slightly bowed elements, the blades extremely long with short, discrete laterally compressed denticles.

Description

Elements assigned to *Ozarkodina excavata excavata* were described by Walliser (1964).

Remarks

Specimens of *O. e. excavata* from Avalanche Lake are similar to the specimens figured by Barrick and Klapper (1976) from Oklahoma. Unlike the Oklahoma specimens, and more typical of *O. e. excavata* from other localities, the anterior process of the Sc element is horizontal or only slightly aborally deflected.

Range

At Avalanche Lake *Ozarkodina excavata excavata* first occurs in the upper *amorphognathoides* Zone, extending through the *bohemica* Zone. The species was also found at AV 7 430 m, in Ludlow-Pridoli strata of the Delorme Formation - Road River

Formation transition.

Material studied

25 Pa, 28 Pb, 5 M, 13 Sc, 10 Sb, 9 Sa.

Ozarkodina gulletensis (Aldridge, 1972)

Plate 3, Figure 13

Pa Element

1972 *Spathognathodus gulletensis* - Aldridge: p. 212-213, Pl. 4, Figs. 9-12.

Pb Element

1972 *Ozarkodina alisonae* - Aldridge: p. 198, Pl. 5, Figs. 4, 6.

M Element

1933 *Prioniodus bicurvatus* - Branson and Mehl: p. 44, Pl. 3, Figs. 9-12.

Sc Element

1953 *Hindeodella equidentata* - Rhodes: p. 303, Pl. 23, Figs. 248, 252-254. Figs. 248, 252-254.

Sb Element

1964 *Synprioniodina silurica* - Walliser: p.88, Pl. 6, Fig. 12; Pl. 8, Fig. 18; Pl. 29, Figs. 38-41; Pl. 30, Figs. 1-4, 6.

Sa Element

1933 *Trichognathus symmetrica* - Branson and Mehl: p. 50, Pl. 3, Figs. 33-34.

Multielement

1975 *Ozarkodina gulletensis* (Aldridge) - Aldridge: Pl. 2, Figs. 7, 8.

1980 *Ozarkodina gulletensis* (Aldridge) - Helfrich: p. 568, Pl. 2, Figs. 21-24, 26-29.

1983 *Ozarkodina gulletensis* (Aldridge) - Uyeno *in* Uyeno and Barnes: p. 21, Pl. 4, Figs. 11-14, 16, 17, 19.

Diagnosis

Only the Pa and Pb elements were assigned. The Pb element is strongly arched and moderately bowed with a short inner process and an outer apical lip below the cusp. The cusp is posteriorly reclined, denticles on the blades are subequal in size, basally fused and posteriorly reclined.

Description

The elements assigned to *O. gulletensis* were described by Aldridge (1972).

Remarks

The Pa and Pb elements are the only diagnostic elements of the apparatus. The M and S transition elements are similar to, or indistinguishable from, the corresponding elements of *O. hadra* and *O. confluens*. Because of the similarity of the elements, M, Sc, Sb, and Sa elements possibly assignable to *O. gulletensis* were included with *O. hadra*, which is more abundant in the Avalanche Lake collection. The range of *O. confluens* does not overlap that of *O. gulletensis* in the Avalanche Lake sections (Fig. 14).

As described by Aldridge (1972), the Pb element of *O. gulletensis* is similar to the Pb of *O. confluens*, but the Pb of *O. confluens* is not as strongly bowed. The Pb elements figured by Aldridge (1972), Helfrich (1980), and Uyeno *in* Uyeno and Barnes (1983) lack the inner process and outer lip below the cusp characteristic of some of the Avalanche Lake specimens. The specimen figured as *O. gulletensis* may be an aberrant form. The specimens of Helfrich (1980) are from the *amorphognathoides* Zone; and those of Uyeno *in* Uyeno and Barnes (1983) occur with *I. inconstans*, indicating a similar age. A number of Avalanche Lake specimens are older, occurring in the *celloni* Zone, the younger specimens (*amorphognathoides* Zone) have reduced marginal processes.

The Pa elements in the Avalanche Lake collection were not complete.

Range

At Avalanche Lake *Ozarkodina gulletensis* first occurs in the *celloni* Zone, ranging into the upper *amorphognathoides* Zone.

Material studied

8 Pa, 10 Pb.

Ozarkodina hadra (Nicoll & Rexroad, 1969)

Plate 5, Figures 1-6

Pa Element

1969 *Spathognathodus hadros* - Nicoll and Rexroad: p. 59, Pl. 5, Figs. 17, 18.

1975 *Ozarkodina hadra* (Nicoll & Rexroad) - Klapper and Murphy: p. 37-38, Pl. 8, Figs. 5, 6.

Diagnosis

The apparatus consists of six distinct form elements. The Pa and Pb are diagnostic, the M and S transition elements are indistinguishable from the corresponding elements of *O. gulletensis* and similar to the elements of *O. confluens*. The Pa consists of a narrow blade, slightly bowed and slightly arched. The posterior half of the blade is lower than the anterior, laterally twisted and deflected slightly downward. A small, flared basal cavity is present at midlength. Denticles are basally fused, laterally compressed, with the tips decreasing in height posteriorly.

Description

Pa element: see diagnosis above. The element has also been described in the literature, a complete description was given by Nicoll and Rexroad (1969).

Pb element: slightly to moderately arched, unbowed blade with a distinct cusp in the posterior half of the element. The anterior blade increases in height toward the cusp, with ten to twelve upright, laterally compressed, basally fused denticles The cusp is posteriorly reclined, twice the length of the next largest denticle. The posterior blade is lower and shorter than the anterior blade, with six denticles, the blade tapering distally.

The M, Sc, Sb, and Sa elements are indistinguishable from the corresponding elements of *O. gulletensis*. See the synonymy of *O. gulletensis* for descriptions of the elements.

Remarks

Ozarkodina hadra has previously only been described from the Pa element. The remainder of the apparatus was thought to be similar to that of *O. confluens* (Klapper and Murphy, 1975; Barrick and Klapper, 1976). The apparatus is indistinguishable from that of *O. gulletensis*, differentiated here because of the abundance of *O. hadra* in relation to *O. gulletensis*. *Ozarkodina confluens* does not occur within the range of *O. hadra* in the Avalanche Lake collection.

The Pa elements of *O. hadra* from Avalanche Lake do not have the large anterior cusp of the holotype, but are like the specimens described by Klapper and Murphy (1975) and Barrick and Klapper (1976) from the western and central United States. The Pb element can be distinguished from the Pb elements of *O. confluens* and *O. gulletensis* by the much less arched blade and less prominent cusp (Fig. 14). As proposed by Barrick and Klapper (1976), *O. hadra* is probably phylogenetically related to *O. confluens*, with *O.*

gulletensis as the oldest form of the lineage. This conclusion was based on the Pa element morphology. The difference in the Pb elements suggests that *O. hadra* has branched from a direct *O. gulletensis* - *O. confluens* lineage. The *O. hadra* line could possibly have converged back to *O. confluens*, becoming ancestral to some of the various morphotypes within the definition of *O. confluens*.

Range

Ozarkodina hadra occurs in the upper *amorphognathoides* Zone at Avalanche Lake.

Material studied

50 Pa, 15 Pb, 6 M, 14 Sc, 13 Sb, 13 Sa.

Ozarkodina hassi (Pollock, Rexroad & Nicoll, 1970)

Plate 1, Figures 1, 2

Pa Element

1970 *Spathognathodus hassi* - Pollock, *et al.*: p. 760, Pl. 111, Figs. 8-12.

Pb Element

1967 *Ozarkodina edithae* Walliser - Rexroad: p. 40, Pl. 2, Fig. 6.

M Element

1967 *Synprioniodina* cf. *Prioniodus bicurvatus* Branson & Mehl - Rexroad: p. 50, Pl. 3, Figs. 9, 10.

Sc Element

1969 *Ligonodina? variabilis* - Nicoll and Rexroad: p. 39, Pl. 4, Figs. 12-14.

Sb Element

1933 *Plectospathodus flexuosus* - Branson and Mehl: p. 47, Pl. 3, Figs. 31, 32.

Sa Element

1967 *Trichonodella* sp. B - Rexroad: p. 53, Pl. 3, Fig. 17.

Multielement

1975 *Ozarkodina hassi* (Pollock, Rexroad & Nicoll) - Cooper: p. 1005, Pl. 3, Figs. 7-12.

1981 *Ozarkodina hassi* (Pollock, Rexroad & Nicoll) - McCracken and Barnes: p. 83, Pl. 7, Figs. 1, 2, 4, 6-13.

1981 *Ozarkodina hassi* (Pollock, Rexroad & Nicoll) - Nowlan: Pl. IV, Figs. 1, 2, 5, 6.

Diagnosis

Multielement *O. hassi* is composed of six distinct form elements. The Pa and Pb elements are distinctive; the M and S transition elements are similar to other simple Lower Silurian *Ozarkodina* species. The Pa consists of a narrow, straight, unarched blade with a cusp behind the midlength, the posterior part of the blade lower than the anterior. Denticles are laterally compressed and basally fused, subequal in height and spacing. The basal cavity is slightly expanded under the cusp.

Description

Elements assigned to *O. hassi* were described by Pollock, *et al.* (1970).

Remarks

Four species of *Ozarkodina* are recognized in the Lower Silurian strata (Member 1W) at Avalanche Lake. *Ozarkodina hassi* is the most numerous, though none of the species are common. The elements assigned to *O. hassi* are similar to the specimens figured by Cooper (1975) from Ohio. The Pb of *O. hassi* is distinguished from the Pb element of *O. oldhamensis* by the reduced arch of the blade. Cooper (1975) stated that the M and S elements of these species are indistinguishable from one another. The Pb element of *O.* n sp. B is shorter compared to *O. hassi* and *O. oldhamensis*, with a moderately bowed blade.

Range

Ozarkodina hassi is the oldest Silurian conodont recognized at Avalanche Lake, and is used to define the base of the Silurian. The species first occurs at AV 4B 111.6 m, stratigraphically lower than any of the Lower Silurian conodont zone index species. Its range extends into the *discreta/kentuckyensis/nathani* Zone.

Material studied

9 Pa, 2 Pb, 2 M, 2 Sc, 1 Sb.

Ozarkodina oldhamensis (Rexroad, 1967)

Plate 1, Figure 7

Pa Element

1967 *Spathognathodus oldhamensis* - Rexroad: p. 49, Pl. 3, Figs. 1, 2.

Pb Element

1967 *Ozarkodina typica* Branson & Mehl - Rexroad: p. 39-40, Pl. 2, Figs. 7, 8.

Multielement

1975 *Ozarkodina oldhamensis* (Rexroad) - Aldridge: Pl. 2, Figs. 16, 17.

1975 *Ozarkodina oldhamensis* (Rexroad) - Cooper: p. 1005-1006, Pl. 3, Figs. 13, 14.

1981 *Ozarkodina oldhamensis* (Rexroad) - McCracken and Barnes: p. 84, Pl. 7, Figs. 3, 5, 14-18.

1982 *Ozarkodina oldhamensis* (Rexroad) - McCracken and Barnes: Pl. 2, Figs. 15, 16.

Diagnosis

Ozarkodina oldhamensis has a six form element assemblage, distinguished by the Pa and Pb elements. The M, Sc, Sb, and Sa elements are indistinguishable from the corresponding elements of *O. hassi* when found together (Cooper, 1975). The Pa element has denticles of equal height on a low blade. The basal cavity is laterally expanded, the flares subequal in size and rounded.

Description

Elements assigned to *O. oldhamensis* have been described in the literature. Complete multielement descriptions were given by Cooper (1975) and McCracken and Barnes (1981).

Remarks

Most of the elements assigned to *O. oldhamensis* are fragmentary, only the Pa, Pb, and M elements are included in the species list. The specimens are similar to the forms figured by McCracken and Barnes (1981) from Anticosti Island.

Range

At Avalanche Lake *Ozarkodina oldhamensis* occurs in the *discreta/kentuckyensis/nathani* Zone.

Material studied

1 Pa, 2 Pb, 1 M.

Ozarkodina n. sp. A

Plate 1, Figures 3-6

Diagnosis

A partial assemblage from one sample is reconstructed; only the Pa, Sc, and Sb elements were assigned. The Pa element is diagnostic, consisting of a slightly bowed, unarched blade with high margins and upright discrete denticles. The basal cavity is widely flared under the cusp, extending posterior to the cusp.

Description

Pa element: the blade is slightly bowed and unarched, expanded at the base of the denticles. The posterior blade is lower than the anterior blade. The cusp is slightly reclined posteriorly, wider than the anterior denticles, but not as long. There are six to seven denticles anterior of the cusp, upright, laterally compressed, closely spaced, and of equal size. The five to six denticles on the posterior blade are lower than the cusp, slightly reclined posteriorly, and not as closely spaced as the anterior denticles. The basal cavity is flared under the cusp, nearly round in outline, tapering posteriorly.

Sc element: hindeodelliform with very thin, slightly arched and bowed posterior process, with laterally compressed, large and closely spaced denticles. The anterior process is deflected downward and approximately 90° laterally to the cusp. Denticles on the process are closely spaced, five to six in number. The cusp is slightly compressed, posteriorly reclined. The basal groove extends from the cusp partly along the posterior blade.

Sb element: plectospathodiform with a thin cusp, strongly arched and slightly bowed. The blades have closely spaced, basally fused denticles. The longer process has eight denticles, the shorter has five. The basal groove is slightly flared under the cusp, extending the length of the short process and part under the long process.

Remarks

Ozarkodina n. sp. A was recognized from one horizon at Avalanche Lake. The species is similar to *O. hassi* and probably closely related.

Range

Ozarkodina n. sp. A occurs in the same sample as the oldest occurrence of a Pa element of *D. kentuckyensis* at Avalanche Lake, within the *discreta*/*kentuckyensis*/*nathani* Zone.

Material studied

2 Pa, 1 Sc, 1 Sb.

Ozarkodina n. sp. B

Plate 1, Figures 8-13

Diagnosis

A species of *Ozarkodina* with the complete apparatus reconstructed, consisting of six skeletal elements: Pa, Pb, M, Sc, Sb, and Sa. The Pa element is diagnostic, consisting of a slightly arched, slightly bowed, short blade. The cusp is large and moderately reclined posteriorly. Denticles are short and fused basally. The basal cavity is flared on the inside under the cusp, and is narrow under the rest of the blade.

Description

Pa element: spathognathodiform, consisting of a short, slightly arched, slightly bowed blade with a large cusp. The cusp is slightly reclined posteriorly, and curved slightly inward, twice the height of the other denticles. The anterior blade has five denticles, which are basally fused, closely spaced and upright. The posterior blade is shorter, with three to four denticles that are basally fused, posteriorly reclined, shorter, and more widely spaced than the anterior denticles. The basal cavity extends the length of the element, and is flared inwardly under the cusp.

Pb element: ozarkodiniform, consisting of a moderately arched, slightly bowed blade with a large central cusp. The anterior blade has five denticles, the denticles becoming larger and more compressed toward the cusp. The posterior blade has four denticles, lower and more widely spaced compared to those on the anterior blade. The cusp is much larger than the denticles, posteriorly reclined and deflected slightly inward. The basal cavity is slightly expanded under the cusp and tapers distally.

M element: synprioniodiform, consisting of a large cusp and two processes of equal height, one short and one longer, both deflected aborally. The cusp is laterally compressed, posteriorly reclined and twisted. The short process has two small denticles, the long process has eight. The denticles are upright relative to the horizontal, the processes are at right angles to each other, joining at the cusp. The basal cavity is expanded under the cusp, with a short inner flare.

Sc element: hindeodelliform, consisting of a large cusp, with a short anterior process and long posterior blade. The cusp is laterally compressed, long and moderately reclined. The anterior process has three to four denticles, the blade only deflected moderately aborally and slightly posteriorly. The posterior process has at least six denticles, laterally compressed, closely spaced and posteriorly reclined. The basal cavity is slightly expanded under the cusp.

Sb element: zygognathiform, consisting of a cusp with two processes, one long, one shorter and higher. The cusp is posteriorly reclined and slightly twisted. The short process has five, closely spaced, fused denticles. The long process has six, larger denticles, not as closely spaced as the denticles on the short process. The basal cavity is expanded under the cusp, with a small posterior projection.

Sa element: trichonodelliform, consisting of a long cusp and two lateral processes. The element is symmetrical, with five denticles on each process, the denticles closest to the cusp are smaller than the others. The angle between the lateral processes is approximately 100°. A short posterior flare extends from the base of the cusp.

Remarks

The elements of *O.* n. sp. B are quite similar to the corresponding elements of *O. hassi*, the M and S elements differing(?) in the expansion of the basal cavity. *Ozarkodina* n. sp. B is probably closely related to the other Lower Silurian, simple ozarkodinids.

Range

Ozarkodina n. sp. B occurs in the lower *discreta*/*kentuckyensis*/*nathani* Zone at Avalanche Lake.

Material studied

2 Pa, 3 Pb, 2 M, 8 Sc, 3 Sb, 1 Sa.

Ozarkodina n. sp. D

Plate 5, Figures 7, 8

Diagnosis

A Pa element which could not be assigned to an apparatus, spathognathodiform, consisting of a small, low, unarched, straight blade with a slight lateral expansion of the blade at the base of the denticles. The cusp is posterior to center, with seven to eight

upright, short, laterally compressed, closely spaced, equal sized denticles on the anterior blade. The cusp is slightly reclined, broader, but only slightly higher than the denticles. The posterior blade is low, decreasing in height away from the cusp, with three triangular denticles. The basal cavity is slightly flared, evenly, on both sides under the cusp.

Description

See Diagnosis.

Remarks

No other elements could be confidently included in an apparatus with the Pa element. Elements are somewhat similar to the Pa element of *O. e. excavata* or *O. polinclinata*, but have fewer denticles and appear to be smaller. This species is similar to the Pa element of *Ozarkodina* sp. C, which was described from an *amorphognathoides* fauna from Wales by Mabillard and Aldridge (1983). The Pa element of *O.* sp. C, figured by Mabillard and Aldridge (Pl. 3, Fig. 10, 1983), differs from *O.* n. sp. D in having a lower blade and more expanded basal flare. The elements are similar in the length of the blade, size and position of the cusp, and morphology of the denticles. They are possibly the same species.

Range

Ozarkodina n. sp. D occurs in the upper *amorphognathoides* Zone at Avalanche Lake.

Material studied

19 Pa.

Ozarkodina n. sp. I

Plate 6, Figures 10-13

Diagnosis

The apparatus, incomplete at present, consists of the Pa and Pb elements. The Pa element has a high blade, subequal denticles, and a small expansion of the basal cavity posterior to center, behind which the blade becomes lower. The Pb element is characterized by high blades, a broad cusp, and small denticles on the subequal blades.

Description

Pa element: spathognathodiform, consisting of a high, flat based, unarched blade, the posterior third lower and slightly curved. The base of the blade is narrow, the upper blade being more robust. Denticles, fifteen to seventeen, are fused basally, laterally compressed and equal in size. The basal cavity is expanded posterior to the midlength, anterior to where the blade becomes lower. The flares over the basal cavity are small, the inner expansion half of the size of the outer.

Pb element: ozarkodiniform, consisting of a slightly arched, slightly bowed element with a large, broad cusp. The cusp is large and wedge shaped, reclined posteriorly. The high anterior blade has five to seven denticles. The five to seven denticles on the posterior blade are smaller than those on the anterior blade. The denticles are basally fused and closely spaced, and much shorter than the cusp. The posterior blade is slightly arched, with the denticles reclined posteriorly. The basal cavity is slightly expanded under the cusp.

Remarks

The Pa element of *Ozarkodina* n. sp. I is suggestive of *Ozarkodina* n. sp. A of Klapper and Murphy (1975) from Nevada, but *O.* n. sp. I has more uniform denticles and a smaller basal expansion. *Ozarkodina* n. sp. A of Klapper and Murphy (1975) is characterized by the "jug handle" appearance of the basal flares when viewed orally, and occurs in the *latialatus* Zone or equivalent zone in Nevada and at Cellon. A relationship of *O.* n. sp. I to *O. confluens* is much more likely, the Pb element being similar to the corresponding element in *O. confluens* (Fig. 14). The lack of recognizable M and S elements may be due to a similarity to *O. confluens* elements and their inclusion under the latter.

Range

Ozarkodina n. sp. I first occurs in the *patula/ranuliformis* Zone, extending to the base of the *bohemica* Zone at Avalanche Lake.

Material studied

10 Pa, 12 Pb.

SUPERFAMILY UNKNOWN

4.9 Family Unknown

4.9.1 Genus *Dapsilodus* Cooper, 1976

Type Species

1933 *Distacodus obliquicostatus* - Branson and Mehl: p. 41, Pl. 3, Fig. 2.

Remarks

Multielement *Dapsilodus* has an apparatus composed of four form elements: M, Sc, Sb, and Sa (Barrick, 1977). The M element is acodiform; Sc through Sa are distacodiform or acodiodiform elements which form a transition series.

Dapsilodus obliquicostatus (Branson & Mehl, 1933)

Plate 2, Figures 22, 23

Sc-Sb Element

1933 *Distacodus obliquicostatus* - Branson and Mehl: p. 41, Pl. 3, Fig. 2.

Sa Element

1971 *Distacodus posterocostatus* - Rexroad and Craig: p. 689, Pl. 81, Figs. 1-4.

Multielement

1971 *Acontiodus obliquicostatus* (Branson & Mehl) - Serpagli: p. 82-84, Pl. 23, Figs. 1-10; Pl. 24, Figs. 1-6.

1976 *Dapsilodus obliquicostatus* (Branson & Mehl) - Cooper: p. 212, Pl. 2, Figs. 10-13, 18-20.

1977 *Dapsilodus obliquicostatus* (Branson & Mehl) - Barrick: p. 50-52, Pl. 2, Figs. 6, 10, 13.

1983 *Dapsilodus obliquicostatus* (Branson & Mehl) - Uyeno *in* Uyeno and Barnes: p. 16, Pl. 9, Figs. 11, 12.

Diagnosis

Elements have a broad, laterally compressed base, tapering to a point of curvature at midheight; and the distal half of the cusp is strongly recurved. The posterior margin of the cusp is keeled; and parallel striae run vertically up the anterior portion of the lower cusp and base.

Description

Elements assigned to *D. obliquicostatus* were described by Cooper (1976).

Remarks

Dapsilodus obliquicostatus occurs through the Silurian and Lower Devonian (Cooper, 1975). At Avalanche Lake the species was only found in Lower Silurian strata, and never in great abundance. Barrick (1983), in a study of post-Llandovery strata from Tennessee, stated that *D. obliquicostatus* was most common in deep-water deposits and probably a planktonic species. It would therefore be expected that *D. obliquicostatus* would be abundant in the shelf / slope deposits at Avalanche Lake. The low abundance in the Lower Silurian, and absence of *D. obliquicostatus* in younger deposits, indicates that the environmental conditions were not suitable for this species during Whittaker-Delorme Formation deposition. *Dapsilodus obliquicostatus* is also rare in deep-water deposits of equivalent age on Anticosti Island (Nowlan, 1983). Where *D. obliquicostatus* does occur it is associated with a deep-water fauna and other deep-water conodonts.

Specimens of *Dapsilodus* not identified to species were referred to as *Dapsilodus* sp. The majority of the specimens are from the sequence containing *D. obliquicostatus*, but the diagnostic element was not recognized.

Range

At Avalanche Lake *Dapsilodus obliquicostatus* first occurs in the horizon of the Ordovician-Silurian boundary, an unzoned interval, extending into the *discreta / kentuckyensis / nathani* Zone.

Material studied

65 elements; 16 *D.* sp. elements.

4.9.2 Genus *Decoriconus* Cooper, 1975

Type Species

1967 *Paltodus costulatus* - Rexroad: p. 40-41, Pl. 4, Figs. 26-29.

Remarks

Multielement *Decoriconus* is composed of a symmetry transition series of elements: Sc, Sb, and Sa (Barrick, 1977). The Sc element is drepanodiform; Sb-Sa is paltodiform-acontiodiform.

Decoriconus fragilis (Branson & Mehl, 1933)

Plate 3, Figure 16

Sc Element

1969 *Drepanodus aduncus* - Nicoll and Rexroad: p. 35, Pl. 7, Figs. 11-15.

Sb-Sa Element

1933 *Paltodus fragilis* - Branson and Mehl: p. 43, Pl. 3, Fig. 6.

Multielement

1976 *Decoriconus fragilis* (Branson & Mehl) - Cooper: p. 212-213, Pl. 2, Figs. 5, 8, 14-17.

1977 *Decoriconus fragilis* (Branson & Mehl) - Barrick: p. 53-54, Pl. 2, Figs. 15, 21-23.

1983 *Decoriconus fragilis* (Branson & Mehl) - Uyeno *in* Uyeno and Barnes: p. 16-17, Pl. 9, Figs. 1-10, 13-16.

Diagnosis

Decoriconus fragilis is composed of one distinct form element (Sc) and a transition series (Sb-Sa) (Barrick, 1977). The Sc element is drepanodiform, the other elements paltodiform. Elements of *D. fragilis* are characterized by a flattened and twisted cone with a wide, oval basal cavity. *Decoriconus fragilis* is recognized from other species of *Decoriconus* by the lack of striae on the Sa element, and lack of ornamentation on other elements. *Decoriconus fragilis* is generally more robust than the similar *Dapsilodus costulatus* (Cooper, 1976; Barrick, 1977).

Description

Elements assigned to *D. fragilis* were described by Cooper (1976).

Remarks

Decoriconus fragilis is similar to *D. costulatus*, which it is closely related to (Cooper, 1976).

Range

Decoriconus fragilis is common, but not abundant in the Avalanche Lake collection, first occuring in the *discreta/kentuckyensis/nathani* Zone, extending to the top of the *amorphognathoides* Zone.

Material studied

113 elements.

4.9.3 Genus *Pseudooneotodus* Drygant, 1974

Type Species

1958 *Oneotodus? beckmanni* - Bischoff and Sannemann: p. 98, Pl. 15, Figs. 22-25.

Remarks

The apparatus of *Pseudooneotodus* is unclear, having been described as single elements, paired elements, in the case of *Pseudooneotodus* n. sp. of Cooper (1977b), with at least three elements in a transition series (Uyeno *in* Uyeno and Barnes, 1983), or associated with *Apsidognathus* (Mabillard and Aldridge, 1983). Elements of *Pseudooneotodus* are conical, either squat or smaller and slender, with one to three denticles. The elements have deep basal cavities.

Pseudooneotodus beckmanni (Bischoff & Sannemann, 1958)

Plate 5, Figure 20

Synonomy

1933 *Oistodus* (?) sp. - Branson and Mehl: Pl. 9, Fig. 3.

1958 *Oneotodus? beckmanni* - Bischoff and Sannemann: p. 98, Pl. 15, Figs. 22-25.

1974 *Pseudooneotodus beckmanni* (Bischoff & Sannemann) - Drygant: p. 67, Pl. 2, Figs. 34-39.

1977b *Pseudooneotodus beckmanni* (Bischoff & Sannemann) - Cooper: p. 1068-1069, Pl. 2, Figs. 14, 17.

1981 *Pseudooneotodus beckmanni* (Bischoff & Sannemann) - Nowlan: Pl. V, Fig. 31.

1981 *Pseudooneotodus beckmanni* (Bischoff & Sannemann) - Nowlan and Barnes: p. 23, Pl. 2, Figs. 20, 21.

1981 *Pseudooneotodus beckmanni* (Bischoff & Sannemann) - McCracken and Barnes: p. 89, Pl. 2, Figs. 30, 31.

Diagnosis

Squat, conical element, the base subrounded or circular, with one denticle.

Description

Elements assigned to *P. beckmanni* were described by Cooper (1977b).

Remarks

Pseudooneotodus beckmanni is recognized by this form only having a single denticle. Elements morphologically between *P. beckmanni* and *P. bicornis* are present, in which the apical surface is ridge like, but without the development of discrete denticles. This form was also noted by Barrick (1977) and Cooper (1977b), being included with *P. bicornis*. The specimens assigned to *P. beckmanni* are uniformly smaller than the other species of *Pseudooneotodus* and the transition form. Following Cooper (1977b) the transition forms are included with *P. bicornis* (see discussion under *P. bicornis*).

Range

Cooper (1977b) gave the range of *P. beckmanni* as Middle Ordovician to Lower Devonian. In the Avalanche Lake collection the species is limited to the *amorphognathoides* Zone.

Material studied

7 elements.

Pseudooneotodus bicornis Drygant, 1974

Plate 6, Figures 19, 20

Synonymy

1966 *Oneotodus* sp. - Spasov and Filipovic: p. 43, Pl. 2, Fig. 6.

1974 *Pseudooneotodus bicornis* - Drygant: p. 67, Pl. 2, Figs. 40-48.

1976 *Pseudooneotodus bicornis* Drygant - Barrick and Klapper: p. 81, Pl. 1, Fig. 15.

1977 *Pseudooneotodus bicornis* Drygant - Barrick: p. 57-58, Pl. 2, Figs. 14, 17, 19, 20.

1977b *Pseudooneotodus bicornis* Drygant - Cooper: p. 1069, Pl. 2, Figs. 8, 9, 11.

1980 *Pseudooneotodus bicornis* Drygant - Helfrich: Pl. 1, Fig. 21.

1983 *Pseudooneotodus bicornis* Drygant - Uyeno *in* Uyeno and Barnes: p. 23, Pl. 3, Figs. ?25, ?26, 27, 28.

Diagnosis

Squat conical element, the base subrounded or circular, with two denticles. Long slender cones with a round cross-section and thick base have been included in the apparatus.

Description

Elements assigned to *P. bicornis* were described by Barrick (1977).

Remarks

Pseudooneotodus bicornis is recognized by its having two apical denticles. Two transition forms occur, elements with an apical ridge without discrete denticles (see Barrick, 1977; Cooper, 1977b), and a tridenticulate form with the third denticle much reduced and recessive. A third, slender element form has been included with *P. bicornis* (Barrick, 1977). Barrick (1977) proposed that *P. biconis* developed from *P. triconis*, the latter losing one of its apical denticles; *P. beckmanni* could develop from *P. bicornis* by the loss of a denticle. The development of *P. beckmanni* from *P. bicornis* is unlikely because *P. beckmanni* precedes *P. bicornis* in the record. Development of *P. bicornis* from *P. tricornis* or *P. beckmanni* is more probable. Another possibility is that *P. beckmanni* is not related to *P. bicornis* or *P. tricornis*. The nature of *P. beckmanni* is different, characteristically smaller and having thinner walls. Cooper (1977b) and Uyeno and Barnes (1983) reported *P. bicornis* in the Llandovery, as old as the *staurognathoides* Zone in the Jupiter Formation, Anticosti Island, Québec. Aldridge (*in* Barrick, 1983) found *P. bicornis* in the *celloni* Zone of Britain. At Avalanche Lake, the first occurrence of a two denticulated *P. bicornis* is after the appearance of *K. ranuliformis*, similar to the range of that form in the Clarita Formation, Oklahoma. Tridenticulated elements, with a reduced third denticle, were assigned to *P. tricornis*. Apical ridged and small slender elements have been assigned to *P. bicornis*.

Range

At Avalanche Lake *Pseudooneotodus bicornis* first occurs at the top of the *amorphognathoides* Zone, extending into the *patula/ranuliformis* Zone.

Material studied

16 elements.

Pseudooneotodus tricornis Drygant, 1974

Plate 5, Figures 21, 22

Synonomy

1974 *Pseudooneotodus tricornis* - Drygant: p. 67, Pl. 2, Figs. 49, 50.

1977 *Pseudooneotodus tricornis* Drygant - Barrick: p. 58, Pl. 2, Fig. 18.

1977b *Pseudooneotodus tricornis* Drygant - Cooper: p. 1069, Pl. 2, Figs. 15, 16.

1983 *Pseudooneotodus tricornis* Drygant - Uyeno *in* Uyeno and Barnes: p. 23, Pl. 6, Figs. 18-20.

Diagnosis

Squat conical elements, with a subrounded or rounded base, and three apical denticles.

Description

Elements assigned to *P. tricornis* have been described by Barrick (1977).

Remarks

Pseudooneotodus tricornis is recognized by its having three apical denticles. A transitional element between *P. tricornis* and *P. bicornis* is included with *P. tricornis*. This element form has three denticles, but the third denticle is recessive and reduced in size, occurring on the side of the cone below the level of the two large denticles. Barrick (1977) suggested that *P. bicornis* evolved from *P. tricornis*, which this transition form supports.

Some of the elements have fine vertical striae on the posterior and lateral sides of the cone. These striae are much smaller and less distinctive than the ridges on *Pseudooneotodus* n. sp. A, and are considered to be a species variation.

Range

Pseudooneotodus tricornis occurs in the *amorphognathoides* Zone at Avalanche Lake.

Material studied

17 elements.

Pseudooneotodus n. sp. A

Plate 5, Figures 24, 25

Diagnosis

Squat conical element with a single denticle. The base is broadly expanded, with a squarish outline. Prominent vertical ridges occur on the sides of the cone, from the base to the top.

Description

Cone with a single denticle, tapering up from a expanded base. The base is squarish in outline with rounded corners. Vertical ridges extend from the basal margin to the apex of the cone. The basal cavity is deeply excavated, extending halfway up inside the cone.

Remarks

Pseudooneotodus n. sp. A is distinguished from other species of *Pseudooneotodus* by obvious vertical ridges and a squarish base. *Pseudooneotodus* n. sp Cooper (1977b) is tuberculated with a round base. A Sc element of *P.* n. sp. Cooper (1977b) figured by Uyeno *in* Uyeno and Barnes (1983) (Pl. 6, Fig. 21) has vertical ridges and a round base. The specimens assigned to *P.* n. sp. A may be part of a larger assemblage with *P.* n. sp. Cooper (1977b).

Squat conical elements with rugae on the base and an irregular cone were included in the apparatus of *Apsidognathus ruginosus* by Mabillard and Aldridge (1983). This form differs from *Pseudooneotodus* n. sp. A in having rugae over the entire element, an irregular cone, and a more rounded basal outline.

Range

Pseudooneotodus n. sp. A occurs in the upper *amorphognathoides* Zone at Avalanche Lake.

Material studied

4 elements.

4.9.4 *Spathognathodus* s.f. Branson and Mehl, 1941

Spathognathodus n. sp. A s.f.

Plate 5, Figures 27, 28

Diagnosis

Spathognathodiform element with a denticulated blade bifurcating into inner and outer processes. The processes are lower than the main blade, with small denticles.

Description

The element is composed of a main blade and two smaller blades diverging from the posterior end of the main blade. A cusp is present at the point of junction of the main blade and two smaller blades. The cusp is slightly larger than the other denticles, with seven on the main blade, which are laterally compressed. The longer lateral blade has six denticles, the short blade has three, generally reduced in size. The main blade is unarched, straight, with smooth margins, the tips of the denticles being of even height. The short inner blade is deflected 140° to the main blade, half the height of the main blade and rounded at the end. The outer process is deflected at 100°, nearly the same length and three-fourths the height of the main blade. The basal cavity is a shallow groove under the length of the blade and processes, slightly expanded under the cusp.

Remarks

This species was described by Mirza (1976) from a collection from the Canadian Arctic Islands, associated with *K. patula*. The Avalanche Lake specimens are older, found in association with an *amorphognathoides* fauna. There is some resemblance between *Spathognathodus* n. sp. A s.f. and *Spathognathodus manitoulinensis* s.f. Pollock, Rexroad & Nicoll (= *Ozarkodina abrupta* Aldridge). In tne elements figured by Pollock, *et al.* (1970), the deflection of the distal blade, blade margin height, denticulation and basal cavity of the specimens are similar to those of *S.* n. sp. A s.f. The difference is that *S. manitoulinensis* s.f. only has one lateral blade, and most of the specimens have a greater expansion of the basal cavity. Specimens described as, "an element with two symmetrical posterior processes", assigned to *Spathognathodus manitoulinensis* s.f., *S.*? n. sp. s.f., were recovered from the Port Nelson Formation from well samples from the Hudson Bay Basin (LèFevre, *et al.*, 1976). This is probably the same species, although no specimens were figured. No other elements could be associated with *S.* n. sp. A s.f., therefore its affinities are questionable, possibly representing a younger form related to *O. abrupta*.

Range

Spathognathodus n. sp. A s.f. occurs in the upper *amorphognathoides* Zone.

Material studied

6 elements.

4.9.5 New Genus B

Type Species

New Genus B n. sp. A

Diagnosis

The apparatus is composed of at least five form elements, chirognathiform, questionably assigned to Pa?, Pb?, Sc?, Sb?, and Sa? positions. The elements are palmate in structure with small basal cavities under the cusp. Blades are arched and bowed, the denticles large, dagger like, and closely spaced with lateral keels on the denticle edges.

New Genus B n. sp. A

Plate 7, Figures 1-7

Multielement

1981 Apparatus A - Uyeno: p. 48, Pl. 9, Figs. 1-6, 12, 13.

Diagnosis

The apparatus is composed of palmate elements with well developed, laterally compressed denticles with sharp keels. The processes are arched and bowed, with a reduced basal cavity under the cusp. The basal plate is commonly present on the bases of the elements.

Description

Elements were questionably assigned to Pa?, Pb?, Sc?, Sb?, and Sa? positions; the M position was left open, although it may be filled by the assigned Pb? element. A complete transition series exists between the Sc? and Sa? elements, possibly including the P elements as well.

Pa? element: strongly arched and moderately bowed blade with large, discrete, dagger like denticles. The cusp is posterior to center, posteriorly reclined, larger than the longest denticle. The anterior blade has six to nine denticles. The posterior blade has three to five denticles, the process deflected downward at almost 90° relative to the anterior blade. The entire blade is generally thin, expanded at the base of the denticles, with a shallow basal groove expanded in a small flare under the cusp.

Pb? element: short, straight, slightly arched blade with an erect posterior cusp. Denticles are large, largely fused with just the apex free, and irregular in height. A small denticle occurs posterior to the cusp. Anterior of the cusp are three to four denticles, one equal in size to the cusp. The basal cavity is expanded under the cusp, tapering toward the ends of the blade.

Sc? element: palmate element, highly arched, with long discrete denticles. The longer denticles on the posterior portion of the blade, the same size as the cusp, are parallel to the anterior process due to the arching of the blade. There are four to five denticles on the short posterior blade, seven to eight denticles anterior to the cusp. Denticles become smaller away from the cusp. The basal cavity is small, often obscured by the basal plate.

Sb? element: palmate element, highly arched with large flattened denticles. The cusp is indistinct because of the large denticles over the basal cavity. The posterior-lateral process is shorter, with five to six closely spaced denticles. The anterior-lateral process has seven denticles. The denticles become smaller and more widely spaced away from the cusp. The basal cavity is narrow, slightly expanded under the cusp.

Sa? element: symmetrical palmate element, with a central cusp with denticles decreasing in size away from cusp. There are four to five denticles on either side of the cusp, commonly the last denticle is larger. The basal cavity is slightly expanded under the cusp.

Remarks

The elements of this apparatus, with the exception of the Pb? element, appear to form a complete transition series Pa?-Sa?. It is possible that the assigned Pb? element corresponds to the M position, and one of the Pa? transition forms fills the Pb? position. The transition series of elements and their lack of similarity to other Silurian forms explains the questionable assignment of the apparatus positions.

New Genus B n. sp. A is similar or identical to the partial assemblage of elements collected by Uyeno (1977, 1981) and described as Apparatus A, with the exception of the M? element which was not recognized. Form elements assigned to *Trichonodella symmetrica* s.f., *Lonchodina greilingi* s.f. and Gen. indet. sp. A from the Upper Silurian ,

Qijang District, China, figured by Wang (1980), appear to correspond to elements assigned to N. Gen. B n. sp. A. The elements of New Genus A n. sp. A are morphologically similar to *Chirognathus*, a Middle Ordovician genus, and, as stated by Uyeno (1981), have a resemblance to *Rhipidognathus symmetricus symmetricus* Branson, Mehl & Branson, a Late Ordovician species. It has been hypothesised that the palmate form elements are an adaptation of shallow water conodontophorids, and not phylogenetically distinctive. The specimens collected by Uyeno (1977, 1981) are from the Cape Storm Formation, Late Silurian, interpreted as shallow-marine limestone and dolostone. Specimens belonging to Apparatus A (Uyeno, 1977), were collected from the Leopold Formation, Late Silurian, which was interpreted as intertidal (Jones and Dixon, 1975, 1977). The Avalanche Lake specimens are from the Delorme Formation, considered here to be deep-water, in the shelf / slope transition area, though proximal to shallow-water environments which existed on the Mackenzie Platform (Morrow, D., GSC, pers. comm., 1984). Possible interpretations are that the species is not restricted to a shallow marine environment; short term conditions were such that shallow water forms moved out onto the shelf; or the conodontophorids / conodonts were transported to the shelf / slope by storm activity or gravity flow. Gravity flow deposits are common at the level where these forms were collected in the Avalanche Lake sections, supporting the shallow-water origin of N. Gen. B n. sp. A and their transport into deeper water. Elements of N. Gen. B n. sp. A are the most abundant form in one sample, which also contains species of *Oulodus?*, *Ozarkodina* and *Panderodus*, indicating a open marine setting. Other samples only contained one element each.

Range

New Genus B n. sp. A occurs in the *patula / ranuliformis* Zone at Avalanche Lake. The specimens described as Apparatus A from the Arctic Islands were dated by Uyeno (1977, 1981, *in* Jones and Dixon, 1975) as Ludlow.

Material studied

34 Pa?, 19 Pb?, 53 Sc?, 18 Sb?, 16 Sa?.

New Genus B? n. sp. B

Plate 6, Figures 23-27

Diagnosis

The apparatus consists of five form elements questionably assigned to the Pa?, Pb?, Sc?, Sb?, and Sa? positions. The elements are strongly arched and bowed. The denticles are elliptical in cross section, robust, long, and sharply pointed with lateral keels.

Description

Pa? element: modified palmate, consisting of a robust, arched, slightly bowed blade with a strong reclined cusp. The anterior blade has four robust denticles, discrete and dagger like. The cusp is reclined so that it is parallel to the anterior blade. The cusp is at least twice as large as the largest denticle, denticles close to the cusp are reduced in size. The posterior blade is shorter than the anterior blade, with four closely spaced denticles. The top margin of the blade is perpendicular to the anterior blade. The basal cavity is expanded under marginal flares beneath the cusp, narrow under the blade.

Pb? element: lonchodiniform(?), consisting of a strongly bowed, strongly arched blade with widely spaced, ovoid denticles and cusp. The anterior blade is inclined, with three large denticles and a smaller, fourth denticle on the tip of the blade. The cusp is erect, inwardly and posteriorly curved. The posterior blade is approximately perpendicular to the anterior blade, with three large denticles. The basal cavity is expanded under the cusp, narrow under the blades.

Sc? element: strongly arched and moderately bowed element with a long central cusp. The cusp is inwardly and posteriorly curved, with lateral keels. The anterior and posterior blades are subequal in length, the angle between the blades approximately 80°. The blades have four denticles each, the middle denticles on the blade larger than the outer denticles. The basal cavity is obscured by the basal plate.

Sb? element: strongly arched and slightly bowed element with a large central cusp. The cusp is posteriorly curved, ovoid in cross-section, with well defined lateral keels. The lateral processes are subequal in length, with an angle of 40° between the blades. Denticles, four on each blade, are closer spaced on the shorter blade, the end denticle on both blades being reduced in size. The basal cavity is slightly flared under the cusp.

Sa? element: symmetrical, strongly arched element with a large, broadly keeled, posteriorly curved cusp. The lateral processes have nearly equant, stout denticles, that are evenly spaced, with the end denticles reduced in size. The basal cavity is slightly

flared under the cusp.

Remarks

New Genus B? n. sp. B is questionably assigned to New Genus B because of the similarity of the denticles to those of New Genus A n. sp. A and the robust, somewhat palmate, form. The similarity may also be a homeomorphic adaptation to a shallow-water environment. There is some similarity of the species to the genus *Oulodus?*, but the collection is too small to make a confident judgement.

The apparatus, as in New Genus B n. sp. A, appears to form a transition series from the Pa? element to the Sa? element. An M element could not be assigned from the collection.

Range

All of the specimens occurred in the sample dominated by New Genus B n. sp. A, within the *patula/ranuliformis* Zone at Avalanche Lake.

Material studied

2 Pa?, 5 Pb?, 3 Sc?, 3 Sb?, 2 Sa?.

4.9.6 Genus and species Indeterminate

Genus and species Indeterminate A

Plate 1, Figure 32

Remarks

A platform element composed of a cusp and four processes. The processes are thin, slightly arched and twisted, coming to sharp ends, and arranged in a cruciform pattern with the cusp at the cross. Denticles are laterally compressed, very closely spaced or fused. The element has some resemblance to *D. kentuckyensis*, which is also cruciform, but Gen. sp. Indet. A has thinner processes, discrete denticles, and a central cusp.

Range

The element occurs in the *discreta/kentuckyensis/nathani* Zone at Avalanche Lake, found in association with *O. oldhamensis*.

Material studied

1 element.

Genus and species Indeterminate C

Plate 5, Figure 26

Remarks

A cruciform element with thick processes and laterally compressed denticles. The blades are twisted with the deeply excavated basal cavity under their entire length. The specimens found were fragmentary.

Range

The specimens occur in the *amorphognathoides* Zone at Avalanche Lake.

Material studied

2 elements.

Genus and species Indeterminate D

Plate 6, Figure 18

Remarks

Large robust cone with an elliptical base and anterior keel. The cone is wide, laterally compressed, and strongly recurved. The nature of the cusp is not known because it has been broken off. The basal cavity extends half the height of the cone.

Range

The species occurs in the *amorphognathoides* Zone at Avalanche Lake.

Material studied

2 elements.

Genus and species Indeterminate E

Plate 7, Figures 15, 16

Remarks

Pb element, consisting of a moderately to strongly arched blade. The cusp is large, posteriorly reclined, and fused to the anterior denticles. The anterior blade is high, consisting of six to seven robust denticles which are largely fused, only the tips are discrete. The posterior process consists of a low narrow bar, with three to four sharp, widely spaced short denticles. The basal cavity extends the length of the element, slightly expanded under the cusp. This form is possibly the Pb element of a late form of the *Ozarkodina confluens* apparatus. The form was always found in association with *O. confluens*.

Range

At Avalanche Lake the specimens occur in the *bohemica* Zone and in the upper part of section AV 7, which is Ludlow or Pridoli.

Material studied

7 elements.

Genus and species Indeterminate F

Plate 7, Figures 18, 21

Remarks

Elements consist of narrow, long blades, with denticles that are short, round in cross-section, blunt, and emergent from the blade in an irregular row, having a "rip-blade" appearance. The form genus *Diplododella* Bassler of Late Devonian age is characterised by irregular denticles. The unfragmented specimens found correspond to S positions in an apparatus. A Sa element with similar denticulation was figured by Uyeno (Pl. 10, Fig. 17, 1981) from the Devon Island Formation.

Range

The species occurs in the *bohemica* Zone at Avalanche Lake.

Material studied

2 elements.

Genus and species Indeterminate G

Plate 7, Figures 19, 23

Remarks

Pb elements consisting of low, thin, strongly arched and slightly bowed blades with a cusp slightly behind center. The cusp is reclined posteriorly, conical in shape, its base wider than the thickness of the blades. The anterior blade has five to six denticles, that are short, round, blunt tipped and widely spaced. The posterior blade is shorter, with three to four similar denticles. The basal cavity extends under the entire element, and is expanded under the cusp.

Range

The species occurs in the *bohemica* Zone at Avalanche Lake.

Material studied

2 elements.

5. PLATES

Plate 1

All magnifications are X36, except Figures 27-32, which are X23. All specimens are from Member 1W, Whittaker Formation. Sample locality and horizon are given after specimen number.

Ozarkodina hassi (Pollock, Rexroad & Nicoll, 1970)
Figure 1: Pa element, lateral view, UA 7343, AV 1, 145 m.
Figure 2: Pb element, lateral view, UA 7344, AV 4B, 111.6 m.

Ozarkodina n sp. A
Figure 3, 4: Pa element: Fig. 3 = oral view, UA 7345, AV 1, 95.5 m; Fig. 4 = lateral view, UA 7346, AV 1, 95.5 m.
Figure 5: Sb element, posterior view, UA 7348, AV 1, 95.5 m.
Figure 6: Sc element, lateral view, UA 7347, AV 1, 95.5 m.

Ozarkodina oldhamensis (Rexroad, 1967)
Figure 7: Pb element, lateral view, UA 7348, AV 1, 110 m.

Ozarkodina n. sp. B
Figure 8: Pa element, lateral view, UA 7349, AV 1, 97.5 m.
Figure 9: Pb element, lateral view, UA 7350, AV 1, 97.5 m.
Figure 10: M element, inner lateral view, UA 7351, AV 1, 97.5 m.
Figure 11: Sc element, lateral view. UA 7352, AV 1, 97.5 m.
Figure 12: Sb element, posterior view, UA 7353, AV 1, 97.5 m.
Figure 13: Sa element, posterior view, UA 7354, AV 1, 97.5 m.

Icriodella discreta Pollock, Rexroad & Nicoll, 1970
Figure 14: Pa element, oral view, UA 7355, AV 1, 95 m.
Figure 18: Pb? element, lateral view, UA 7356, AV 1, 95 m.

Oulodus? nathani McCracken & Barnes, 1981
Figure 15: Pa element, lateral view, UA 7357, AV 1, 101 m.

Oulodus? kentuckyensis (Branson & Branson, 1947)
Figure 16: Pa element, lateral view, UA 7358, AV 1, 97.5 m.
Figure 17: Pb element, lateral view, UA 7359, AV 1, 97.5 m.

Oulodus? fluegeli (Walliser, 1964)
Figure 19: Pa element, inner aboral view, UA 7360, AV 1, 124.5 m.
Figure 20: Pb element, lateral view, UA 7361, AV 1, 124.5 m.
Figure 21: M element, lateral view, UA 7362, AV 1, 124.5 m.
Figure 22: Sc element, lateral view, UA 7363, AV 1, 124.5 m.
Figure 23: Sb element, posterior view, UA 7364, AV 1, 124.5 m.
Figure 24: Sa element, posterior view, UA 7365, AV 1, 124.5 m.
Figure 25: Pa-Sa? element, outer aboral view, UA 7366, AV 1, 124.5 m.
Figure 26: Sc-Sb? element, lateral view, UA 7367, AV 1, 124.5 m.

Distomodus kentuckyensis Branson & Branson, 1947
Figure 27: Pa element, oral view, UA 7368, AV 1, 101 m.
Figure 28: Pb element, lateral view, UA 7369, AV 1, 97.5 m.
Figure 29: M element, posterolateral view, UA 7370, AV 1, 97.5 m.
Figure 30: Sc element, lateral view, UA 7371, AV 1, 97.5 m.
Figure 31: Sb-Sa element, posterior view, UA 7372, AV 1, 97.5 m.

Genus and species Indeterminate A
Figure 32: Pa element, oral view, UA 7373, AV 1, 110 m.

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Plate 2

Magnifications are X36 for Figures 1-8, 21; X23 for Figures 9-20; X45 for Figures 22, 23. All specimens are from Member 1W and Member 3W, Whittaker Formation. Sample locality and horizon are given after the specimen number.

Pterospathodus celloni (Walliser, 1964)
Figure 1: Pa element, oral view, UA 7374, AV 1, 347.5 m.

Astropentagnathus irregularis Mostler, 1967
Figure 2: Pa_1 element, oral view, UA 7375, AV 1, 320 m.
Figure 3: Pa_2 element, oral view, UA 7376, AV 1, 320 m.
Figure 4: Pb_1 element, posterolateral view, UA 7377, AV 1, 336 m.
Figure 5: S element, posterior view, UA 7379, AV 1, 320 m.
Figure 6: Pb_2 element, lateral view, UA 7378, AV 1, 340.8 m.
Figure 7: S? element, posterior view, UA 7380, AV 1, 336 m.

Astropentagnathus aff. *A. irregularis* Mostler, 1967
Figure 8: Pa_1 element, oral view, UA 7381, AV 2, 11.5 m.

Distomodus staurognathoides (Walliser, 1964)
Figure 9: Pa element, oral view, UA 7382, AV 1, 452 m.
Figure 10: Pb element, oral view, UA 7383, AV 1, 421 m.
Figure 11: M element, posterolateral view, UA 7384, AV 1, 347.5 m.
Figure 12: Sc element, lateral view, UA 7385, AV 1, 347.5 m.
Figure 13: Sb element, lateral view, UA 7386, AV 4, 0 m.
Figure 14, 15: Sa element: Fig. 14 = posterior view, UA 7387, AV 4, 1 m; Fig. 15 = lateral view, UA 7388, AV 4, 1 m.
Figure 16-18, 20: *"Johnognathus"* element: Fig. 16 = oral view, UA 7389, AV 1, 460 m; Fig. 17 = oral view, UA 7390, AV 4, 12 m; Fig. 18 = oral view, UA 7391, AV 1, 460 m; Fig. 20 = lateral view, UA 7392, AV 4, 12 m.
Figure 19: Sa-*"Johnognathus"* element, oral view, UA 7393, AV 4, 0 m.

Walliserodus sancticlairi Cooper, 1976
Figure 21: *"dyscritus"*, lateral view, UA 7394, AV 1, 97.5 m.

Dapsilodus obliquicostatus (Branson & Mehl, 1933)
Figure 22: *"obliquicostatus"* element, lateral view, UA 7395, AV 1, 97.5 m.
Figure 23: *"posterocostatus"* element, lateral view, UA 7396, AV 1, 97.5 m.

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Plate 3

All magnifications are X36, except Figures 16, 18, 19, 24, which are X45; Figures 22, 23, which are X23; Figure 25, which is X90. All specimens are from Member 1W and Member 3W, Whittaker Formation. Sample locality and horizon are given after the specimen number.

Aulacognathus bullatus bullatus (Nicoll & Rexroad, 1969)
Figure 1: Pa element, oral view, UA 7397, AV 2, 13 m.
Figure 2: Pb element, lateral view, UA 7398, AV 2, 63 m.

Aulacognathus bullatus n. ssp. A
Figure 3: Pa element, oral view, UA 7399, AV 1, 421 m.

Aulacognathus aff. *A. latus* (Nicoll & Rexroad, 1969)
Figure 4: Pa element, oral view, UA 7400, AV 1, 417.5 m.

Aulacognathus n. sp. A
Figure 5: Pa element, oral view, UA 7401, AV 1, 417.5 m.

Aulacognatrhus kuehni Mostler, 1967
Figure 6: Pa element, oral view, UA 7402, AV 1, 347.5 m.

Aulacognathus n. sp. B
Figure 7: Pa element, oral view, UA 7403, AV 2, 156 m.

New Genus A n. sp. A
Figure 8-10: Pa_1 element: Fig. 8 = oral view, UA 7404, AV 2, 63 m; Fig. 9 = aboral view, UA 7405, AV 2, 63 m; Fig. 10 = oral view, UA 7406, AV 2, 63 m.
Figure 11, 12: Pa_2 element: Fig. 11 = oral view, UA 7407, AV 2, 63 m; Fig. 12 = aboral view, UA 7408, AV 2, 63 m.

Ozarkodina gulletensis (Aldridge, 1972)
Figure 13: Pb element, lateral view, UA 7409, AV 1, 320 m.

New Genus A n. sp. B
Figure 14, 15: Pa_1 element: Fig. 14 = oral view, UA 7410, AV 1, 417.5 m; Fig. 15 = aboral view, UA 7411, AV 2, 127 m.

Decoriconus fragilis (Branson & Mehl, 1933)
Figure 16: posterolateral view, UA 7412, AV 1, 124.5 m.

Panderodus spp.
Figure 17: (*"recurvatus"* element), lateral view, UA 7413, AV 1, 118.5 m.
Figure 22: (large *"simplex"* element), lateral view, UA 7414, AV 1, 421 m.
Figure 23: (large *"unicostatus"* element), lateral view, UA 7415, AV 1, 421 m.

Bellodella sp. A Miller, 1978
Figure 18: Form a, inner lateral view, UA 7416, AV 1, 450 m.
Figure 19: Form b, inner lateral view, UA 7417, AV 1, 450 m.
Figure 24: Form d, inner lateral view, UA 7419, AV 1, 450 m.
Figure 25: Form c, inner lateral view, UA 7418, AV 1, 450 m.

Panderodus unicostatus (Branson & Mehl, 1933)
Figure 20: "*simplex*" element, lateral view, UA 7420, AV 1, 124.5 m.
Figure 21: "*unicostatus*" element, lateral view, UA 7421, AV 1, 97.5 m.

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Plate 4

All magnifications are X36. All specimens are from Member 3W, Whittaker Formation. Sample locality and horizon are given after the specimen number.

Pterospathodus amorphognathoides Walliser, 1964
Figure 1, 2: Pa element: Fig. 1 = oral view, UA 7422, AV 2, 156 m; Fig. 2 = oral view, UA 7423, AV 1, 421 m.
Figure 3: Pb element, lateral view, UA 7424, AV 2, 156 m.

Pterospathodus pennatus procerus (Walliser, 1964)
Figure 4: Pa element, oral view, UA 7425, AV 2, 152 m.

Pterospathodus pennatus n. ssp. A
Figure 5: Pa element, oral view, UA 7426, AV 2, 152 m.

Apsidognathus tuberculatus Walliser, 1964
Figure 6, 7: Pa_1 element: Fig. 6 = oral view, UA 7427, AV 1, 452 m; Fig. 7 = oral view, UA 7428, AV 1, 346 m.
Figure 8: Pa_2 element, oral view, UA 7429, AV 1, 421 m.
Figure 9: Pb_1 element, oral-oblique view, UA 7430, AV 1, 421 M.
Figure 10: Pb_2 element, aboral-oblique view, UA 7431, AV 4, 1 m.
Figure 11: S element, oral/posterior view, UA 7432, AV 4, 0 m.

Apsidognathus n. sp. A
Figure 12: Pa_1 element, oral view, UA 7433, AV 1, 455 m.

Oulodus? n. sp. 1
Figure 13, 16: Pa element: Fig. 13 = outer lateral view, UA 7434, AV 1, 347.5 m; Fig. 16 = inner aboral view, UA 7435, AV 1, 347.5 m.
Figure 14: Pb element, lateral view, UA 7436, AV 1, 347.5 m.
Figure 15: Sc element, lateral view, UA 7438, AV 1, 347.5 m.
Figure 17: M element, lateral view, UA 7437, AV 1, 347.5 m.
Figure 18: Sa element, posterior view, UA 7440, AV 1, 347.5 m.
Figure 19: Sb element, posterior view, UA 7439, AV 1, 347.5 m.

Oulodus? n. sp. C
Figure 20: Pa element, lateral-aboral view, UA 7441, AV 1, 320 m.
Figure 21: Pb element, oral oblique view, UA 7442, AV 1, 320 m.
Figure 22: M element, lateral view, UA 7443, AV 1, 341 m.
Figure 23: Sc element, lateral view, UA 7444, AV 1, 320 m.
Figure 24: Sb element, posterior oblique view, UA 7445, AV 1, 320 m.
Figure 28, 29: Sa element: Fig. 28 = posterior view, UA 7446, AV 2, 13 m; Fig. 29 = oral oblique view, UA 7447, AV 1, 341 m.

Carniodus carnulus Walliser, 1964
Figure 25: Pa element, lateral view, UA 7448, AV 4, 1 m.
Figure 26, 27: Pbv element: Fig. 26 = oral view, UA 7449, AV 4, 0 m; Fig. 27 = lateral view, UA 7450, AV 4, 0 m.

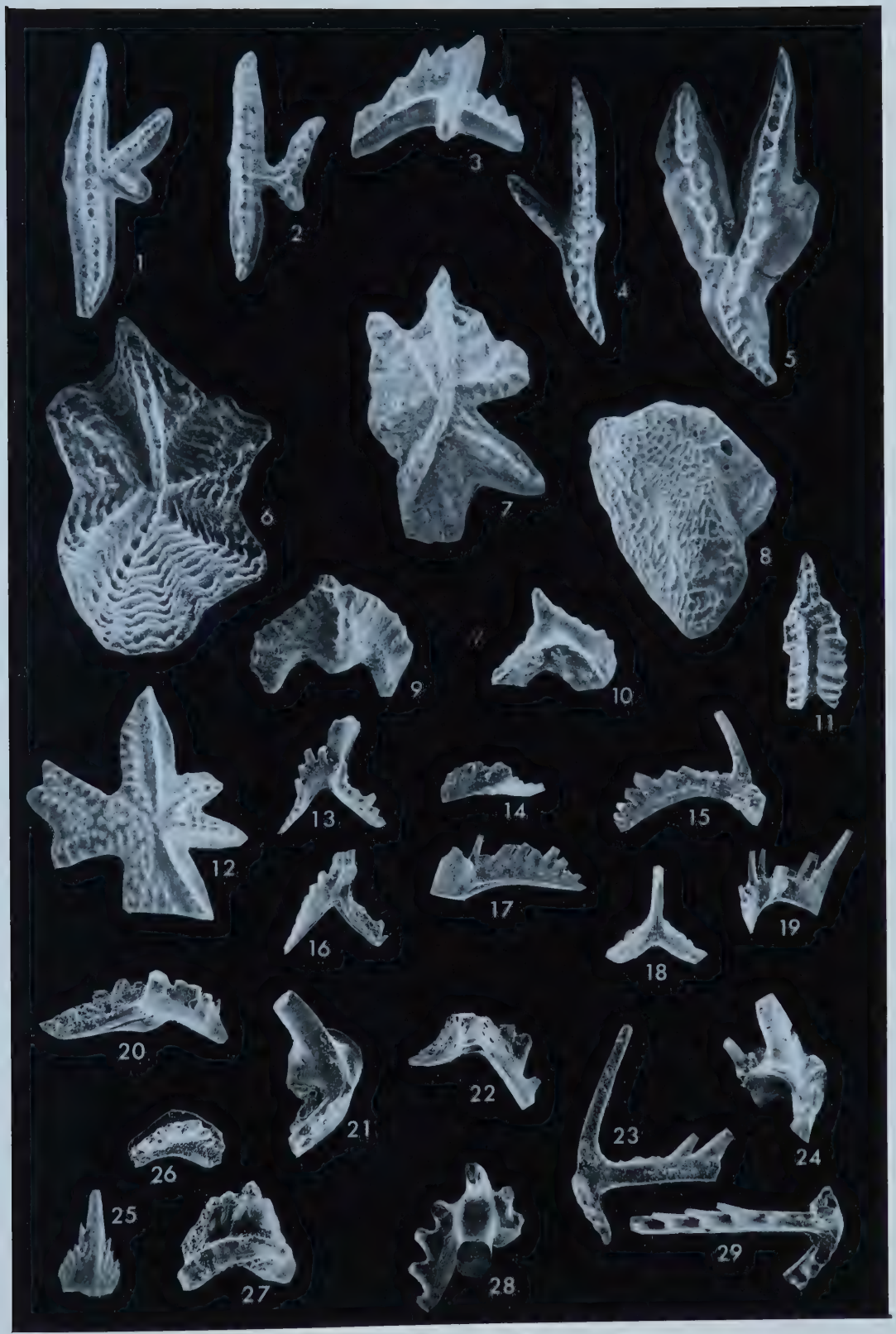
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Plate 5

All magnifications are X36, except Figures 20-22, 24, 25, which are X72. All specimens are from Member 3W, Whittaker Formation. Sample locality and horizon are given after the specimen number.

Ozarkodina hadra (Nicoll & Rexroad, 1969)
Figure 1: Pa element, lateral view, UA 7451, AV 2, 152 m.
Figure 2: Pb element, lateral view, UA 7452, AV 1, 421 m.
Figure 3: M element, lateral view, UA 7453, AV 2, 152 m.
Figure 4: Sc element, lateral view, UA 7454, AV 1, 460 m.
Figure 5: Sb element, posterior view, UA 7455, AV 2, 157 m.
Figure 6: Sa element, posterior view, UA 7456, AV 1, 460 m.

Ozarkodina n. sp. D
Figure 7, 8: Pa element: Fig. 7 = oral view, UA 7457, AV 4, 1 m; Fig. 8 = lateral view, UA 7458, AV 4, 0 m.

Oulodus? n. sp. 2
Figure 9: Pa element, aboral-inner oblique view, UA 7459, AV 4, 1 m.
Figure 10: Pb element, lateral view, UA 7460, AV 4, 1 m.
Figure 11: M element, lateral view, UA 7461, AV 4, 1 m.
Figure 12: Sc element, lateral view, UA 7462, AV 4, 1 m.
Figure 13: Sb element, posterior view, UA 7463, AV 4, 1 m.
Figure 14: Sa element, posterior view, UA 7464, AV 1, 450 m.
Figure 15: Pa-Sa? element, lateral view, UA 7465, AV 1, 450 m.
Figure 16: Sb-Sa? element, inner / lateral view, UA 7466, AV 4, 1 m.

Oulodus? n. sp. D
Figure 17: Pa element, lateral-aboral oblique view, UA 7467, AV 2, 156 m.
Figure 18: Pb? element, lateral view, UA 7468, AV 2, 156 m.
Figure 19: Sc element, lateral view, UA 7469, AV 2, 156 m.
Figure 23: Sa element, posterior view, UA 7470, AV 2, 156 m.

Pseudooneotodus beckmanni (Bischoff & Sannemann, 1958)
Figure 20: squat cone, oral view, UA 7471, AV 1, 347.5 m.

Pseudooneotodus tricornis Drygant, 1974
Figure 21, 22: Fig. 21 = three denticle squat cone, oral view, UA 7472, AV 1, 460 m; Fig. 22 = three denticles with reduced third denticle squat cone, oral view, UA 7473, AV 2, 63 m.

Pseudooneotodus n. sp. A
Figure 24, 25: striated squat cone: Fig. 24 = oral view, UA 7474, AV 4, 1 m; Fig. 25 = lateral view, UA 7475, AV 4, 1 m.

Genus and species Indeterminate C
Figure 26: Pa element, oral view, UA 7476, AV 1, 417.5 m.

Spathognathodus n. sp. A s.f.
Figure 27, 28: Pa element: Fig. 27 = oral view, UA 7477, AV 1, 455 m; Fig. 28 = lateral view, UA 7478, AV 2, 157 m.

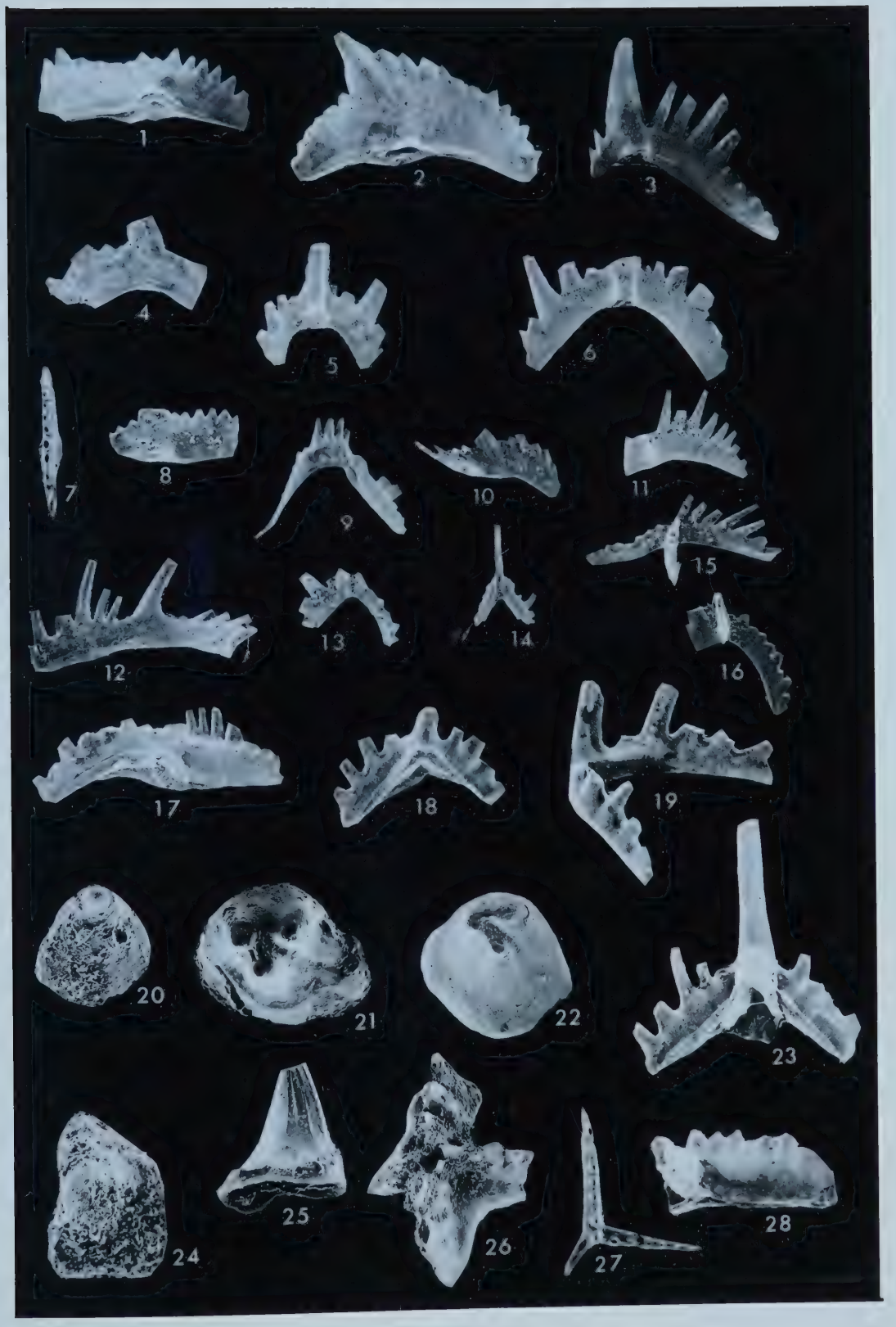
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Plate 6

All magnifications are X36, except Figures 19, 20, which are X72. All specimens are from Member 3W, Whittaker Formation, and Member 2D, Delorme Formation. Sample locality and horizon are given after specimen number.

Kockelella ranuliformis (Walliser, 1964)
Figure 1: Pa element, oral view, UA 7479, AV 4, 12 m.

Kockelella patula Walliser, 1964
Figure 2: Pa element, oral view, UA 7480, AV 2, 242 m.

Kockelella absidata Barrick & Klapper, 1976
Figure 3, 4: Pa element: Fig. 3 = lateral view, UA 7481, AV 2, 274 m; Fig. 4 = oral oblique view, UA 7481, AV 2, 274 m.
Figure 6: Pb element, lateral view, UA 7482, AV 2, 274 m.
Figure 7: M element, lateral view, UA 7483, AV 4, 150.5 m.

Kockelella walliseri (Helfrich, 1975)
Figure 5: Pa element, oral view, UA 7484, AV 4, 240 m.

Ozarkodina excavata excavata (Branson & Mehl, 1933)
Figure 8: Pb element, lateral view, UA 7485, AV 6, 258 m.
Figure 9: Sc element, lateral view, UA 7486, AV 6, 258 m.

Ozarkodina n. sp. I
Figure 10, 11: Pa element: Fig. 10 = lateral view, UA 7487, AV 2, 256 m; Fig. 11 = oral view, UA 7488, AV 4, 150.5 m.
Figure 12, 13: Pb element: Fig. 12 = lateral view, UA 7489, AV 2, 256 m; Fig. 13 = lateral view, UA 7490, AV 2, 256 m.

Oulodus? n. sp. F
Figure 14: Pa element, lateral-aboral oblique view, UA 7491, AV 2, 274 m.
Figure 15: Pb element, lateral view, UA 7492, AV 4, 150.5 m.
Figure 16: M element, lateral view, UA 7493, AV 2, 274 m.
Figure 17: Sc element, lateral view, UA 7494, AV 4, 150.5 m.
Figure 21: Sa element, posterior oblique view, UA 7496, AV 4, 150.5 m.
Figure 22: Sb element, posterior oblique view, UA 7495, AV 4, 150.5 m.

Genus and species Indeterminate D
Figure 18: cone element, lateral view, UA 7497, AV 1, 441 m.

Pseudooneotodus bicornis Drygant, 1974
Figure 19: squat cone element, oral view, UA 7498, AV 2, 274 m.
Figure 20: slender conical element, lateral view, UA 7499, AV 1, 460 m.

New Genus B? n. sp. B
Figure 23: Pa? element, lateral view, UA 7500, AV 4, 136 m.
Figure 24: Pb? element, lateral view, UA 7501, AV 4, 136 m.
Figure 25: Sc? element, lateral view, UA 7502, AV 4, 136 m.
Figure 26: Sb? element, posterior view, UA 7503, AV 4, 136 m.
Figure 27: Sa? element, posterior view, UA 7504, AV 4, 136 m.

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Plate 7

All magnifications are X36. All specimens are from Member 2D and Member 3D, Delorme Formation and Road River Formation. Sample locality and horizon are given after the specimen number.

New Genus B n. sp. A
Figure 1, 2: Pa? element: Fig. 1 = lateral view, UA 7505, AV 4, 136 m; Fig. 2 = lateral view, UA 7506, AV 4, 136 m.
Figure 3: Pa?-Pb? element, lateral view, UA 7507, AV 4, 136 m.
Figure 4: Pb? element, lateral view, UA 7508, AV 4, 136 m.
Figure 5: Sc? element, lateral view, UA 7509, AV 4, 136 m.
Figure 6: Sb? element, posterior view, UA 7510, AV 4, 136 m.
Figure 7: Sa? element, posterior view, UA 7511, AV 4, 136 m.

Ozarkodina bohemica (Walliser, 1964)
Figure 8: Pa element, oral view, UA 7512, AV 4, 231 m.

Ozarkodina confluens (Branson & Mehl, 1933)
Figure 9, 10, 12, 13: Pa element: Fig. 9 = gamma morphotype, lateral view, UA 7513, AV 4, 240 m; Fig. 10 = gamma morphotype, lateral view, UA 7514, AV 6, 250 m; Fig. 12 = beta morphotype, lateral view, UA 7515, AV 5, 190 m; Fig. 13 = epsilon morphotype, lateral view, UA 7516, AV 7, 430 m.
Figure 11: Pb element, lateral view, UA 7517, AV 4, 240 m.

Oulodus? n. sp. I
Figure 14: Pa? element, lateral-aboral oblique view, UA 7518, AV 4, 231 m.
Figure 17: Pb element, posterior view, UA 7520, AV 5, 209 m.
Figure 20: Sc element, lateral view, UA 7519, AV 5, 209 m.

Genus and species Indeterminate E
Figure 15, 16: Pb element: Fig. 15 = lateral view, UA 7521, AV 6, 250 m; Fig. 16 = lateral view, UA 7522, AV 4, 231 m.

Genus and species Indeterminate F
Figure 18: M-S element, lateral view, UA 7523, AV 5, 190 m.
Figure 21: S element, posterior view, UA 7524, AV 6, 250 m.

Genus and species Indeterminate G
Figure 19, 23: Pb element: Fig. 19 = lateral view, UA 7525, AV 6, 250 m; Fig. 23 = lateral view, UA 7526, AV 6, 250 m.

Pelekysgnathus arcticus Uyeno, 1980
Figure 22: I element, lateral view, UA 7527, AV 7, 430 m.

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7. APPENDIX 1

Section Descriptions

Sections measured and sampled on the northern limb of the Avalanche Syncline, Glacier Lake map-area (95L), in 1978, 1979 and 1983 are described. The sections extend laterally approximately 10 km in a northwest trend. Thicknesses are in meters, see Figure 1 for locations of sections.

AV 1

Location: 62° 24'N, 127° 04'W

The measured sections are along the main tributary of Thundercloud Creek, due east of Avalanche Lake. AV 1 is exposed in a deep gully and ridge on the south side of the valley. The section is 21.4 km, N23E of the 6572' benchmark south of Avalanche Lake, and 26.6 km, N80E of the 7122' benchmark west of Avalanche Lake.

Total thickness: 620 m

Base: Limestone, black-grey weathering medium grey below a 3 m covered interval, appears as a prominent dark unit jutting into the stream.

Top: Massive light grey dolostone.

Collected and measured by: B.D.E. Chatterton and D.G. Perry, 1978, 1979, further collections by B.D.E. Chatterton and D.J. Over, 1983.

Delorme Formation

601-620+

Dolostone, light grey weathering creamy grey, resistant, blocky weathering thick to very-thick beds, medium-coarse crystalline, crinoidal, some brachiopods, fetid.

600-601

Limestone, medium grey weathering medium grey, slightly recessive, thin (2-4 cm) platy beds, crinoidal.

598-600

Limestone, medium grey weathering light to creamy grey, resistant(?), thick beds, massive blocky weathering, coarse grained encrinite, fetid.

582-598

Limestone, black weathering black, recessive, very argillaceous, micritic, few silicified brachiopods, bryozoans and trilobites.

579.5-582

Limestone, light grey weathering light creamy grey, resistant, thickly bedded, blocky weathering, coarse grained encrinite, fetid.

573-579.5

Limestone, black weathering dark grey-buff, recessive, very argillaceous, very-thin platy beds, few corals, brachiopods, non-silicified.

566-573

Limestone, medium grey weathering light creamy grey, resistant, massive very thick beds, blocky weathering, coarse grained crinoidal, fetid, locally abundant non-silicified brachiopods.

522-566

Shale, black weathering yellow-brown, recessive, very thinly bedded, becoming more calcic upward.

465-522

Shale, dark grey weathering yellow-brown, slightly recessive, slightly calcic, highly cleaved at low angle to bedding, thinly laminated, platy, locally with limonitic horizons and papery, fish horizon at approximately 515 m.

456-465

Covered, talus is yellow-brown slightly calcareous shale. Sample from 460 m.

Whittaker Formation

446-456

Limestone, dark grey weathering medium grey, slightly recessive, microcrystalline, some medium grained crinoidal calcarenite beds, thin regular bedding, few silicified horizons with brachiopods and trilobites.

436-446

Limestone, dark grey-black weathering medium grey, resistant, thin to medium

(6-15 cm) beds, very argillaceous, microcrystalline, fetid, few silicified brachiopods and pelmatozoan debris. Samples from 445 m, 440 m.

432-436

Covered.

411-432

Limestone, black weathering dark grey, moderately recessive, poorly exposed, platy-flaggy, very-thin to thin beds, microcrystalline, locally medium grained bioclastic, fetid, abundant silicified brachiopods, corals and trilobites. 417-417.5 m, 414 m.

397.5-411

Limestone, dark grey-black weathering medium grey, resistant, thinly bedded microcrystalline, fetid, few poorly preserved brachiopods and pelmatozoan debris.

393-397.5

Covered.

366.5-393

Limestone, dark grey weathering medium-light grey, recessive, very-thin to thin flaggy beds, locally crinoidal medium grained calcarenite, although mostly microcrystalline, few thin (1 cm) black chert lenses, 10% of unit is very thin highly cleaved calcareous shale interbeds, local silicified trilobites.

346.5-366.5

Limestone, dark grey weathering dark grey, slightly to very argillaceous, thin flaggy beds, bedding nodular, moderatley resistant, minor black chert lenses.

336-346.5

Limestone, dark grey weathering dark grey, resistant, thin to medium (6-20 cm) beds, slightly to very argillaceous, interbeds (10%) of very thin (1cm) calcareous shale, microcrystalline, fetid, abundant silicified material.

303-336

Covered, local outcrop at 320 m of cherty dark grey limestone.

285-303

Dolostone and black chert, interbedded, dolomite is medium grey weathering light grey, fine crystalline, fetid, thin to medium (8-15 cm) bedded, 40-60% chert, locally

with fine laminations; unit very resistant, blocky weathering banded beds.

260-285

Dolostone, medium grey weathering medium grey, resistant, very-fine crystalline, thinly bedded, 40% thin black chert interbeds, blocky weahering banded beds, unfossiliferous.

252-260

Limestone, medium grey weathering light grey, resistant, very thin beds, very siliceous, abundant grey chert lenses and stringers, limestone is very fine crystalline with very fine laminations, fetid.

227-252

Covered, section measured is now 250 m along strike to the northwest where exposed in the stream cut.

189-227

Limestone, medium grey weathering medium grey-orange, commonly with limonitic stain, very resistant, thin regular bedding, blocky weathering, microcrystalline, no visible fossils, 40% black chert and silicic bands in nodules, lenses and thin (to 6 cm) beds, locally sightly dolomitic near 215 m, some beds with thin silicic laminations.

178-189

Covered.

173-178

Limestone, dark grey weathering medium grey-buff, recessive, very argillaceous, microcrystaline, thin to medium bedding, fetid, abundant silicic pods and thin lenses.

167-173

Limestone, very poorly exposed, black weathering dark grey, very recessive, thin to medium (3-15 cm) beds, very argillaceous, microcrystalline, fetid.

155-167

Covered.

147-155

Limestone, dark grey-black weathering dark grey, recessive, thin (3-6 cm) beds, some to 15 cm, platy, microcrystalline.

139-147

Limestone, black weathering dark grey, resistant, thin to medium bedding, argillaceous, locally thickly laminated, highly veined with calcite, fetid.

124-139

Covered.

116.5-124

Limestone, black weathering dark grey, resistant, medium bedded, microcrystalline, abundant 0.5-2 cm silica nodules, fetid.

110-116.5

Covered.

106-110

Limestone, dark grey-black weathering black, very resistant, thin to medium (6-20 cm) bedded, microcrystalline, 30-60% black chert beds, lenses and nodules, more chert and slightly phosphatic upward.

100-106

Limestone, black weathering dark grey, resistant, thin to medium (6-15 cm) regular beds, micritic, locally grading to medium grained calcarenite. At 102 m abundant crushed graptolite impressions, abundant 0.5-2 cm silicic nodules, commonly spherical, sometimes connected, minor 1-2 cm black chert stringers, abundant small brachiopods, locally bryozoan hash on bedding surfaces.

92-100

Limestone, dark grey weathering light grey-buff, resistant, thin (5-12 cm) beds, micritic, slightly argillaceous, silicified trilobites.

84.5-92

Limestone, dark grey weathering buff-brown, very thin-thin (1-6 cm) beds, moderately resistant, thin laminations on weathered surfaces, microcrystalline, argillaceous, silicified brachiopods and trilobites.

77.5-84.5

Covered. The Ordovician-Silurian boundary is within this interval.

71-77.5

Limestone, medium grey weathering light grey, resistant, medium to thick (10-40cm) beds, microcrystalline, locally micritic, slightly argillaceous, silicified trilobites.

68-71

Covered.

64-68

Limestone, black weathering medium grey, resistant, medium bedded, micritic, very argillaceous, strongly cleaved.

56-64

Mudstone, black weathering medium grey, moderately resistant, thin to medium (8-15 cm) beds, calcareous, minor black chert lenses.

41-56

Mudstone-argillaceous limestone, black weathering light to dark grey, locally buff-grey, moderately resistant, thinly bedded, locally irregular, 1-4 cm chert stringers increase upward to nodules and lenses with local convolute bedding.

37.5-41

Limestone, dark grey weathering grey-black, resistant, massive thick to very-thick (50-150 cm) beds, nodular, micritic, locally bioclastic, abundant bryzoans and ostracodes.

27-37.5

Limestone, black weathering dark grey, moderately resistant, thin to medium (8-15 cm) nodular bedding, micritic, locally bioclastic, argillaceous.

13-21

Limestone, medium grey weathering medium grey-brown, moderately resistant, thin to medium irregular beds, medium grained calcarenite of pelmatozoan, brachiopod and bryzoan debris, some micritic interbeds.

10-13

Covered.

0-10

Limestone, black-grey weathering medium grey, moderately resistant(?), thin (6-12 cm) irregular and nodular beds, fine crystalline, argillaceous, abundant bryozoans, locally pelmatozoans, corals and trilobites.

AV 2

Location: 62° 24'N, 127° 04'W

West rim of gully measured for AV 1.

Total thickness: 370 m

Base: Top of uppermost resistant cherty dolomite banded beds.

Top: Massive light grey dolostone.

Collected and measured by: B.D.E. Chatterton and D.G. Perry, 1978, 1979.

Delorme Formation

332.5-370

Dolostone, light grey weathering creamy grey, very resistant, very thick beds, massive, coarse grained encrinite, porous, abundant large pelmatozoan ossicles.

327-332.5

Limestone, black weathering grey-yellow, very thin beds, moderately recessive, microcrystalline, very argillaceous, uneven bedding, abundant lingulids, few bryozoans, articulate brachiopods and acrotretids.

287-327

Dolostone, light grey weathering creamy grey, thick to very thick beds, resistant, blocky weathering, fine to medium crystals, pelmatozoan rich, some beds of coarse limestone encrinite, common large pelmatozoan ossicles, few large pentamerid brachiopods and ?megalomid pelecypods.

279.5-287

Covered.

274-279.5

Limestone, black weathering dark grey, locally maroon, thin (2-8 cm) beds, recessive, microcrystalline, flaggy, fetid, abundant silicified brachiopods and trilobites.

271-274

Dolostone, light grey weathering light creamy white, thick (30-150 cm) beds, massive, resistant, fetid, almost entirely pelmatozoan debris.

268-271

Limestone, black weathering dark grey, thin (2-5 cm) beds, slightly resistant, microcrystalline, fetid, cherty and dolomitic upward with maroon weathering, few silicified trilobites.

245-268

Poorly exposed to covered, thinly bedded black limestone at 255 m, silicified trilobites; thin dark grey chert beds at 248.5 m.

240-245

Limestone, dark grey weathering medium grey, thin beds, slightly recessive, interbeds of calcareous shale, abundant coarse bioclastic debris, brachiopods, corals, sponges and trilobites.

239-240

Limestone, light grey weathering same, 1 m bed, biostromal, resistant, coarse bioclastic debris, abundant solitary rugose and tabulate corals, pelmatozoan ossicles, stromatoporoids, *Favosites, Halysites,* and *Heliolites.*

236-239

Poorly exposed, yellow-orange slightly calcareous shale talus.

231-236

Shale, dark grey weathering yellow-brown, thin laminations, moderately resistant, slightly calcareous, highly cleaved at low angle to bedding.

225-231

Covered.

165-225

Shale, dark grey weathering yellow-brown, fine laminations, moderately recessive, few very argillaceous limestone beds, especially near 203 m, 1 m thick bed contains abundant fish, inarticulate brachiopods and conulariids.

Whittaker Formation

160-165

Limestone, dark grey weathering rusty brown, thin beds, recessive, medium-coarse grained calcarenite, rubbly, abundant brachiopod, pelmatozoan and trilobite debris.

136-160

Limestone, black weathering dark grey, thin beds, moderately resistant(?), microcrystalline, argillaceous, minor black chert near top, bioclastic, abundant silicified brachiopods and corals.

123-136

Covered.

116-123

Limestone, black weathering medium grey, thin (3-4 cm) beds, moderately resistant, common calcareous shale interbeds.

96-116

Interbedded limestone and shale, thin (lst.) to very thin (sh.) beds, moderately resistant, fetid.

92-96

Covered.

65-92

Limestone, dark grey-black weathering light grey, thin (1-4 cm) beds, recessive, platy, micritic, very argillaceous.

52-65

Limestone, black weathering dark grey, thin-medium (8-12 cm) beds, resistant, micritic, argillaceous, thin interbeds of shaly limestone common.

32-52

Limestone, black weathering dark grey, thin beds(?), resistant, argillaceous, abundant black chert nodules (2-4 cm), minor calcareous shale interbeds, chert and shale increases upward, silicified bioclastic debris.

21-32

Covered.

9.5-21

Limestone, dark grey weathering medium grey, thin (2-4 cm) beds, recessive, flaggy / platy, microcrystalline, pelletoid, silicified fossils.

0-9.5

Limestone, black weathering medium grey, thin beds, resistant, microcrystalline, some small black chert nodules, few silicified brachiopods, pelloidal.

0

Base of section is top of interbedded black chert and dolomite banded beds.

AV 4

Location: 62° 23'N, 127°03'W

Deep gully cut by next stream (v's on 1:250,000 map) east of AV 1.

Total thickness: 275 m

Base: 14 m below base of brown shale unit.

Top: Massive light grey dolostone.

Collected and measured by: B.D.E. Chatterton and D.G. Perry, 1979.

Delorme Formation

275+

Dolostone, light grey weathering grey and orange grey, very resistant, thick bedded, massive.

263-275

Limestone, medium grey weathering medium grey, thin bedded, moderately resistant, minor shaly and dolomitic horizons, brachiopods, crinoids, and fish common, pentamerid brachiopods common toward top.

251-263

Dolomitic limestone, medium grey weathering orangy grey, thin to medium beds, slightly recessive, platy, crinoids, fish, ostracodes, and nautiloids common.

219-251

Limestone, medium grey weathering brownish grey, thin to medium beds (2-12 cm), slightly argillaceous and silty fossiliferous micrite, fish, ostracodes, trilobites common.

197-219

Limestone, medium grey weathering brownish grey, thin beds, slightly argillaceous and silty fossiliferous micrite, pelletal, crinoid ossicles abundant, fish common.

187-197

Interbedded limestone and shale; limestone, medium grey weathering light grey, thin beds, biosparite, brachiopods, crinoids, ostracodes, trilobites common, some fish. Shale, medium grey weathering brownish grey, thinly bedded, moderately recessive,

calcareous, poorly fossiliferous.

184-187

Argillaceous limestone, medium grey weathering brownish grey, thin beds, slightly resistant, micrite replaced by microspar, brachiopods, crinoids, fish, nautiloids, ostracodes, and trilobites present.

174-184

Limestone, medium light grey weathering medium light grey, thin irregular beds, moderately resistant, biosparite, abundant brachiopods and crinoid ossicles.

162-174

Covered, talus consists of thin bedded limestone, medium grey weathering medium light grey, biosparite with abundant brachiopods and crinoid ossicles, some pelecypods and trilobites.

150-162

Limestone, medium grey weathering medium light grey, thin irregular beds (2-5 cm), slightly resistant, bioclastic sparite, crinoids, fish common, some trilobites.

140.5-150

Covered.

136-140.5

Limestone, medium grey weathering light grey, thin to medium beds (3-12 cm), slightly recessive, fossiliferous micrite and sparite, bryozoans, crinoids, ostracodes, trilobites commom, some fish.

131-136

Limestone, medium grey weathering medium light grey, thin to thick beds, resistant, biosparite, abundant crinoid ossicles.

126-131

Limestone, medium dark grey weathering medium grey with purplish tinge, thin to medium beds (3-12 cm), slightly resistant, micrite and biosparite, brachiopods, bryozoans, crinoids, ostracodes, sponges, and trilobites common. (This is the horizon collected by A. Lenz in 1974, Avalanche Lake 300-330 ft (Lenz, 1977; Copeland, 1978).

115-126

Covered.

95.5-115

Interbedded shale and argillaceous limestone, medium grey weathering light brown grey, thin beds, slightly recessive, some brachiopods, crinoids, graptolites, nautiloids.

43-91

Shale, medium grey weathering yellowish buff grey and brownish grey, thinly bedded, laminated and fissile, calcareous, rare inarticulate brachiopods, graptolites and nautiloids.

42.5-43

Shale, black, finely laminated, recessive, some graptolites and nautiloids.

16-42.5

Shale, medium grey weathering yellowish buff grey, finely laminated, recessive, calcareous, unfossiliferous.

14.5-16

Shale, black, thinly bedded, recessive, some crinoid debris, brachiopods, and graptolites.

Whittaker Formation

14-14.5

Limestone, medium dark grey weathering grey with maroon tinge, irregular bedding, recessive, abundant brachiopods, bryozoans, fish, ostracodes, trilobites, rare corals.

12-14

Limestone, medium grey weathering medium grey with purplish tinge, thin beds, resistant, bioclastic microspar, brachiopods, crinoids, and gastropods common.

0-12

Limestone, medium grey weathering medium grey with reddish tinge, very-thin to thin bedded (1-6cm), bioclastic micrite and microspar, brachiopods and crinoids are common. This interval was collected by A. Lenz in 1974, Avalanche Lake 675-685 ft (Lenz, 1977; Copeland, 1978).

AV 4B

Location: 62° 23'N, 127° 03'W

Deep gully cut by next stream (v's on 1:250,000 scale) east of AV 1. Section is opposite flat sided peak north of valley. This section is approximately 300 m below the base of AV 4.

Total thickness: 155 m

Base: Where gully opens into slope below series of small (2-5 m) waterfalls. Dark grey-black limestone above light grey unit.

Top: Resistant cherty dolo-limestone banded beds.

Collected and measured by: B.D.E. Chatterton and D.J. Over, 1983. (AV 4 continues above, collected and measured by B.D.E. Chatterton and D.G. Perry, 1979.)

Whittaker Formation

154.5+

Limestone and black chert, resistant, massive with thin laminated micrite beds, spar replaced corals.

119.5-154.5

Shale and limestone, limestone dark grey weathering medium grey, argillaceous, thin (5-8 cm) beds, micritic, some microspar replacement, shales are dark grey weathering dark grey, calcareous, medium (10-15 cm) beds. The unit is moderately recessive to recessive, limestone beds becoming dominant above 130 m with nodular black chert appearing, shale beds thinner, graptolitic, flaggy to platy, silicified brachiopods, crinoids and trilobites, *Leonaspis* at 128.5 m and 134.5 m.

118.5-119.5

Shale, dark grey weathering medium grey, recessive-covered, very thin beds, calcareous.

111.5-118.5

Limestone, dark grey weathering medium grey, moderately recessive, thin uneven beds, argillaceous micrite, some microspar, platy. The Ordovician-Silurian boundary is between 111.6 m and 111.0 m (Nowlan, pers. comm., 1983).

110.85-111.5

Limestone, two units, A 110.85-111.3, B 111.3-111.5. A, dark grey weathering medium grey, moderately resistant, massive, locally replaced by microspar, locally nodular, cherty, unfossiliferous, lies disconformably over lower unit. B, dark grey weathering medium grey, moderately resistant, massive, micrite replaced by microspar, silicified corals and trilobites.

107-110.85

Limestone, medium grey weathering medium grey, very thin (0.5-2 cm) beds, wavy, argillaceous micrite replaced by microspar, platy, *Cryptolithus* and *Anataphrus* common.

106.5-107

Limestone, medium grey weathering medium grey, moderately resistant, massive, medium beds, wavy, micrite, some beds largely fine crystalline spar, *Lingula* and *Anataphrus* rare.

91.5-106.5

Limestone, dark grey weathering medium grey, thin to medium (2-15 cm) beds, wavy, micrite, some microspar replacement, argillaceous, platy, *Lingula*, *Cryptolithus* and *Anataphrus* present.

81-91.5

Limestone, dark grey weathering light grey, moderately resistant, thin beds, wavy, micrite, some replacement by fine crystalline spar, 20% of beds are black chert, *Robertia* and *Anataphrus* present.

75.5-81

Limestone and shale, interbedded, medium grey weathering light grey, moderately recessive, thin beds, wavy, limestone is argillaceous, shale calcareous, weathered surfaces laminated, black chert appears in very thin (0.5-2 cm) discontinuous horizons at 70 m, nodular upward, *Cryptolithus*, *Robertia* and *Anataphrus* present.

56-75.5

Limestone, dark grey weathring dark grey, moderately recessive, thin to medium beds with thick interbeds (form waterfalls), micrite, some microspar replacement, argillaceous, flaggy.

50-56

Limestone, dark grey-black weathering dark grey, moderately recessive, thick bedded, massive, some thin to medium beds, micrite, some microspar, weathers to crumbly uneven flags.

41.5-50

Limestone, dark grey weathering medium grey, moderately resistant, thin to medium (5-20 cm) beds, wavy, appears massive, thinner beds are argillaceous, laminated, microspar and fine spar replacement.

39-41.5

Covered.

28-39

Limestone, dark grey weathering medium grey, moderately recessive, thin beds, wavy, micrite, some fine spar replacement, totally fine to medium spar above 35 m.

23-28

Limestone, medium grey weathering medium grey, resistant, thick beds, massive, micrite, very little microspar replacement, appears mottled from white dolomite and silica replacement of fractures and fossils, beds thin into upper unit.

22.5-23

Covered, thinly bedded argillaceous micrite talus.

17.8-22.5

Limestone, medium grey weathering light brown-grey, resistant, thin to thick beds, medium crystalline sparite, weathers to blocky slabs.

16-17.8

Limestone, medium grey weathering medium grey (?), moderately recessive, thin beds, wavy, micrite, corals.

0-16

Limestone, dark grey-black weathering dark grey, moderately resistant, medium beds, micrite, microspar and fine crystalline spar replacement, argillaceous.

0

Top of medium-thick bedded massive light grey limestone, separated from unit below by short covered interval.

AV 5

Location: 62° 23'N, 127° 03'W

Open slope east of gully east of AV 4B. Characterized by prominant dark limestone beds between shaly units. Measured section forms ridge.

Total thickness: 225 m

Base: Base of lower resistant limestone beds above brown shale unit.

Top: Resistant light grey dolostone.

Collected and measured by: B.D.E. Chatterton and D.J. Over, 1983.

Delorme Formation

224+

Dolostone, light grey weathering light grey, resistant, massive, some bedding, fine crystalline.

214-224.5

Limestone, dark grey-black weathering dark grey, resistant, thin (6-10 cm) uniform beds, wavy, micrite, partial dolomitization, silicified brachiopods and crinoids.

189-214

Limestone, medium grey weathering light grey, resistant, thin to medium bedded, massive, wavy, bioclastic micrite, occasional thin (5-10cm) dark grey shale interbeds, some partial dolomitization, silicified brachiopods and crinoids, fish, some silicified trilobites.

177-189

Shale and limestone, dark grey weathering light brown shale with interbedded medium grey weathering orange-brown micrite, moderately recessive, thin to medium beds, uneven, shales platy, limestone contains crinoids, trilobites and fish.

134-177

Shale, dark grey weathering light brown, moderately recessive, very thin beds, platy, calcareous, rare bioclastic micrite throughout, abundant silicified brachiopods, crinoids, and trilobites, fish; conulariids in shale.

91.5-134

Shale, dark grey weathering light brown, recessive, very thin beds, platy, calcareous, abundant conulariids and *Lingula*, rare fish and trilobites in upper calcareous horizons.

68.8-91.5

Shale, dark grey-black weathering medium grey, recessive, very thin beds, platy, calcareous, conulariids, fish, graptolites and inarticulate brachiopods, articulate brachiopod and fish debris at base.

61.5-68.8

Limestone, dark grey weathering light grey, resistant, medium bedded, uneven, crumbly, coarse bioclastic spar, some micritic beds with microspar replacement, dominantly crinoidal with brachiopods, corals and trilobites.

59-61.5

Limestone, largely covered, argillaceous micrite, some thin sparry beds, weathers to flaggy and platy fragments.

55-59

Limestone, dark grey weathering medium grey, recessive, thin (6-10 cm) beds, uneven, micrite, some fine crystalline spar replacement, platy, abundant Cythaspid fish plates oriented convex up.

46.5-55

Limestone, dark grey weathering brown, resistant, medium beds, uneven, micrite, argillaceous, laminated, interbedded with thicker beds of coarse bioclastic spar, abundant brachiopods, crinoids and trilobites.

45-46.5

Limestone, recessive to covered, thinly bedded, flaggy-platy, probably argillaceous micrite.

32-45

Limestone, interbedded micrite and bioclastic spar, dark grey and medium grey weathering medium grey, resistant, massive, medium to thick beds, uneven, micrite beds generally thinner, some microspar replacement, brachiopods, crinoids and trilobites common.

30-32

Limestone, recessive to covered, probably argillaceous.

26.4-30

Limestone, mediuum grey weathering medium grey, resistant, thin to medium beds, coarse bioclastic micrite, some medium grained spar replacement, abundant brachiopod and crinoidal debris, sharp contact at base.

25-26.4

Limestone, medium grey weathering medium grey, recessive, thin to medium beds, uneven, micrite, abundant argillaceous horizons, some microspar replacement, bioclastics appear near top.

22.5-25

Limestone, medium grey weathering light grey, resistant, massive, medium to thick beds, coarse bioclastic micrite, largely spar replaced, abundant crinoids, brachiopods and trilobites.

19.7-22.5

Limestone, dark grey weathering light grey-buff, moderately resistant, thin beds, uneven, micrite, very little microspar replacement, some thinner argillaceous beds, laminated, unit appears banded.

17.7-19.7

Limestone, medium grey weathering light grey, resistant, massive, thin to medium (6-15 cm) beds, uneven, bioclastic micrite, largely replaced by medium spar, thin dark grey interbed near top, recessive, silicified brachiopods and crinoids.

13.8-17.7

Limestone, dark grey weathering medium grey, moderately recessive, medium bedded with thin interbeds, wavy, micrite, some microspar replacement, thin beds argillaceous, laminated, nodular appearance of upper micrite beds from soft sediment deformation, silicified brachiopods, corals, crinoids, ostracodes and trilobites.

7.5-13.8

Limestone, covered, talus is similar to upper unit.

7-7.5

Limestone, dark grey weathering medium grey, moderately resistant, medium beds,

wavy, micrite, some microspar replacement, scatterd bioclastic horizons, silicified brachiopods, bryozoans, ostracodes and trilobites.

5-7

Covered, talus of flaggy and platy argillaceous limestone.

4-5

Limestone, dark grey weathering medium grey, moderately recessive, thin to medium (5-15 cm) beds, uneven, micrite, some microspar replacement, silicified brachiopods, bryozoans, ostracodes and trilobites.

0-4

Shale, dark grey weathering brown, moderately recessive, very thin beds, calcareous, cleaved at low angle, locally articulated crinoid stems.

0

Upper section of thick brown shale unit. Entire exposure is approximately 50 m thick, correlates to "brown shale" of AV 1.

AV 6

Location: 62° 23'N, 127° 03'W

Open slope east of AV 5, characterized by prominent limestone beds between shaly units. Measured section forms ridge in line with north trending valley east of flat sided peak north of main valley.

Total Thickness: 260 m

Base: Base of lower resistant limestone beds above brown shaly unit.

Top: Resistant light grey limestone.

Collected and measured by: B.D.E. Chatterton and D.J. Over, 1983.

Delorme Formation

260+

Dolostone, grey, resistant, massive, bioclastic material largely replaced.

253-260

Limestone, medium grey weathering medium light grey, resistant, medium beds, bioclastic sparite, some dolomitization, nautiloids and crinoids present.

237-253

Limestone, dark grey weathering medium grey, resistant, thin to medium beds, interbedded biomicrites and biosparites, with purplish argillaceous bedding planes, some horizons with algal structures, brachiopods and pelmatozoan debris common, some nautiloids and fish material.

235.7-237

Limestone and shale, medium grey-buff weathering same, slightly recessive, thin beds, micrite, some bioclastic debris, shale calcareous, abundant brachiopods and crinoids.

230-235.7

Limestone, dark grey weathering dark grey, resistant, thin to medium beds, uneven, biomicrite and biosparite, purple bedding surfaces, brachiopods, mollusks, and pelmatozoan debris common.

223-230

Limestone, medium grey weathering medium grey-buff, moderately resistant, thin to medium beds, micrite(?), some thin interbedded calcareous shale, some brachiopods and crinoids.

208-233

Limestone, largely covered.

122-208

Shale, dark grey weathering orange-buff, moderately resistant, very thin beds, calcareous, platy, cleaved at low angle to bedding, abundant *Lingula* and burrows, conulariids and nautiloids, some micritic interbeds containing brachiopods and crinoids, fish debris more common upward.

96-122

Shale, covered, probably similar to above unit.

76.5-96

Shale, dark grey weathering dark grey, recessive, thin beds, laminated, calcareous, some poorly preserved graptolites.

76.5-82.5

Limestone, medium grey weathering medium grey-buff, resistant, thick beds, some very thin (1-3 cm) interbeds, biomicrite to biosparite, abundant pelmatozoan debris.

72.5-76.5

Limestone, medium grey to light grey weathering same, orange where dolomitized, resistant, thick beds, recrystalized sparite, partially dolomitized.

66-72.5

Limestone, medium grey weathering medium grey-buff, moderately recessive, thin beds, micrite, some spar replacement, silicified brachiopods, bryozoans, corals, crinoids, mollusks and trilobites.

59-66

Limestone, medium grey weathering medium grey, moderately resistant, medium to thick beds, biosparite, abundant brachiopods and pelmatozoans, fish common in upper beds.

56-59

Limestone, medium grey weathering buff-grey, moderately recessive, thin beds, thin

laminae, argillaceous, some bioclastic material, brachiopods, pelmatozoans.

42-56

Limestone, medium grey weathering medium grey, moderately recessive, thin beds, biosparite, some biomicrite, locally argillaceous, laminated.

31.5-42

Limestone, medium grey weathering medium grey, moderately resistant(?), thin to medium beds, wavy, interbedded micrite and biosparite, some soft sediment deformation, pelmatozoans abundant in sparite.

30-31.5

LImestone, grey weathering buff-grey, resistant, thick beds, biosparite, some thin micrite interbeds, wavy, some soft sediment deformation, abundant pelmatozoan debris.

25.5-30

Limestone, grey weathering grey-buff, moderately recessive, thin beds, micrite, argillaceous, some laminated calcareous shale interbeds, bioclastic horizons contain pelmatozoan debris, solitary corals, weathers into rubbly blocks.

23-25.5

Limestone, grey weathering light grey-buff, resistant, thick to very thick beds, massive, biosparite, styolitic bedding surfaces, abundant pelmatozoan debris.

5-23

Limestone, medium grey weathering medium grey-buff, moderately recessive, thin (2-7 cm) beds, micrite, argillaceous, silicified brachiopods, bryozoans, corals and ostracodes.

0-5

Limestone, grey weathering buff-grey, moderately recessive, thin beds, micrite(?), argillaceous, locally shaly, unfossiliferous.

0

Base of section is the top of a thick (80 m) buff-brown shale unit.

AV 7

Location: 62° 22'N, 126° 56'W

High ridge trending NNE in line with and across large stream to the southeast from AV 1-6. Ridge is at right angle to strike of beds, sawtooth in a series of blocky limestone beds and less resistant shales.

Total thickness: 492 m

Base: Slightly resistant bed of limestone in argillaceous micrite, north of main saddle on ridge.

Top: Medium grey shale, south of main saddle on ridge.

Collected and measured by: B.D.E. Chatterton and D.J. Over, 1983.

Road River - Delorme Formation

381-492

Shale, medium grey to dark grey weathering orange-brown, slightly recessive(?), thin beds, calcareous, medium interbeds of bioclastic limestone locally, medium grey weathering medium grey, silicified brachiopods and crinoids common, laminated dolomite weathering pinkish brown from 414-420 m.

350-381

Shale, dark grey weathering dark grey, some orange-brown, slightly recessive, thin beds, laminated, calcareous, weathers to coarse lathes, unfossiliferous.

325-350

Shale, black weathering dark grey-black, recessive, thin beds, laminated, calcareous, some bioclastic micrites, abundant brachiopods and crinoids, some silicification.

321-325

Limestone, medium grey weathering light grey, recessive, medium to thick beds, micritic to sparry, bioclastic, some deformed shale rip-up clasts, abundant brachiopods, crinoids and fish.

302-321

Limestone, medium grey weathering medium grey-buff, slightly recessive, thin beds, micrite, argillaceous, laminated, silicified brachiopods and trilobites.

291-302

Shale, grading upward into argillaceous limestone, medium grey weathering orange-buff and grey, slightly recessive, thin beds, calcareous, unfossiliferous.

268-291

Limestone, medium grey weathering medium grey-buff, slightly resistant, thin to medium (2-15 cm) beds, micrite, some calcareous shale interbeds, unfossiliferous.

260.5-268

Limestone, grey weathering light grey(?), resistant, thin to medium beds, irregular, silicified brachiopods, crinoids and trilobites.

256.5-260.5

Limestone, medium grey weathering medium grey, slightly recessive, thin beds, micrite, argillaceous, shaly beds common, weathers into angular shards, unfossiliferous.

255.6-256.5

Limestone, medium grey weathering medium grey, slightly resistant, medium beds, sparry, micritic at base and top, silicified brachiopods, corals, crinoids, mollusks and trilobites, some fish.

255.5-255.6

Phosphatic limestone, irregular bedding surfaces, black fine phosphate nodules, crusty on upper / lower bedding surface, some nautiloids.

250-255.5

Shale, dark grey weathering light grey, recessive, weathers into angular shards, interbedded nodular limestone (20%), pyritic, unfossiliferous.

194-250

Shale and interbedded limestone, medium grey weathering orange-buff-grey, slightly recessive, shale is calcareous, thin bedded, poorly laminated, weathers into angular shards; limestone is thin to medium (4-15 cm) bedded, micritic, argillaceous, unfossiliferous.

104-194

Shale, medium grey to dark grey weathering orange-buff, slightly resistant, thin beds, laminated, calcareous, weathers to angular shards, unfossiliferous.

83-104

Shale, dark grey weathering dark grey to orange-brown, moderately recessive(?), thin bedded, laminated, calcareous, weathers to angular shards, unfossiliferous.

71-83

Shale, black weathering dark grey, recessive, thin beds, laminated, calcareous, weathers to plates, angular shards at top.

1-71

Limestone, medium grey to dark grey weathering medium grey, slightly resistant, very-thin to thin (0.5-10 cm) beds, argillaceous, some calcareous shale interbeds, locally limestone nodules, fish debris common at 70 m, silicified horizons rare, brachiopods, crinoids, trilobites and some nautiloids.

0-1

Limestone, dark grey weathering medium grey, slightly resistant, thin beds, argillaceous, laminated, weathers to fine angular plates.

0

Base of section is unit of argillaceous micrite, 0 m is first occurrence of fossiliferous beds, crinoidal.

8. APPENDIX 2

Samples were collected from AV 1, AV 2, AV 4, AV 4B, AV 5, AV 6, and AV 7 in 1978, 1979, and 1983. Samples collected in 1978 and 1979 were largely processed by B.D.E. Chatterton and D.G. Perry, some 1978 and 1979, and 1983 samples were processed by D.J. Over.

List of samples processed.

SAMPLE Section/Horizon/Date	MASS (kg)	NUMBER OF CONODONTS	ELEMENTS per kg	NUMBER OF SPECIES
AV 1 85 m 1983	2.2	--	--	--
AV 1 90 m 1983	1.4	--	--	--
AV 1 92 m 1979	3.7	4	1	3
AV 1 95 m 1983	2.0	7	4	4
AV 1 95.5 m 1978/79	9.9	25	3	8
AV 1 97.5 m 1978	1.9	258	136	11
AV 1 101 m 1979	5.0	58	10	8
AV 1 103.5 m 1983	2.2	3	<1	3
AV 1 106.5 m 1978	1.2	2	1	2
AV 1 107 m 1979	4.6	2	<1	2
AV 1 110 m 1979	3.9	5	1	3
AV 1 118.5 m 1979	4.5	29	6	4
AV 1 120 m 1983	2.1	7	3	2
AV 1 124 m 1978	2.6	198	76	5
AV 1 124.5 m 1978/83	4.4	207	47	9
AV 1 130 m 1979	3.4	2	<1	1
AV 1 133 m 1983	1.3	--	--	--
AV 1 145 m 1983	1.2	7	6	3
AV 1 150 m 1983	1.0	14	14	6
AV 1 165 m 1983	1.0	14	14	4
AV 1 174.5 m 1978	3.5	2	<1	1
AV 1 185 m 1983	1.0	--	--	--
AV 1 200 m 1983	0.5	--	--	--
AV 1 210 m 1983	0.7	--	--	--
AV 1 230 m 1983	0.5	--	--	--
AV 1 240 m 1983	0.9	--	--	--
AV 1 251 m 1983	0.7	--	--	--
AV 1 260 m 1983	0.5	--	--	--
AV 1 300 m 1983	0.4	--	--	--
AV 1 320T m 1978/83	15.4	354	23	13
AV 1 336T m 1978	69.6	612	9	23
AV 1 340.8 m 1978	1.5	124	83	10
AV 1 341T m 1978/79	19.0	70	4	12
AV 1 346 m 1978	4.7	108	23	9
AV 1 347.5 m 1983	1.0	465	465	23

cont.

SAMPLE Section/Horizon/Date	MASS (kg)	NUMBER OF CONODONTS	ELEMENTS per kg	NUMBER OF SPECIES
AV 1 366 m 1978	7.5	5	<1	3
AV 1 370 m 1983	1.1	1	1	1
AV 1 376 m 1983	1.0	9	9	4
AV 1 385 m 1983	1.5	7	4	2
AV 1 395 m 1983	1.1	2	2	2
AV 1 401 m 1983	1.0	6	6	3
AV 1 405 m 1983	1.9	52	26	6
AV 1 411T m 1978	6.2	7	1	6
AV 1 414 m 1978	4.5	110	24	13
AV 1 417.5 m 1978	11.0	274	25	14
AV 1 418 m 1979	8.2	38	4	11
AV 1 419 m 1978	8.4	86	10	14
AV 1 421 m 1978	4.6	230	50	14
AV 1 430 m 1983	1.2	12	10	6
AV 1 434.5 m 1983	1.9	85	45	5
AV 1 440 m 1983	0.9	8	9	2
AV 1 441 m 1978	5.5	2	<1	2
AV 1 445 m 1983	0.9	--	--	--
AV 1 450 m 1983	1.4	336	240	14
AV 1 453 m 1983	1.4	54	39	8
AV 1 455 m 1978	18.2	261	14	16
AV 1 456 m 1983	1.1	--	--	--
AV 1 460 m 1978	5.6	401	72	16
AV 1 480 m 1983	1.0	11	11	3
AV 2 6.5 m 1979	3.6	5	1	2
AV 2 9.0 m 1979	5.4	430	80	12
AV 2 11.5 m 1979	3.9	179	46	8
AV 2 13T m 1978	5.0	63	12	8
AV 2 17T m 1978	24.6	294	11	15
AV 2 47 m 1978	18.9	344	18	18
AV 2 63 m 1978	9.2	555	60	15
AV 2 127 m 1978	---	86	--	12
AV 2 152 m 1978	---	299	--	16
AV 2 156 m 1978	9.5	92	10	9
AV 2 157 m 1978	10.5	334	32	18
AV 2 160 m 1978	2.4	10	4	4
AV 2 242 m 1978	3.7	40	10	7
AV 2 256 m 1978	10.8	64	6	6
AV 2 260T m 1978	6.7	21	3	5
AV 2 269 m 1978	3.0	35	11	4
AV 2 274 m 1978	50.1	288	6	9
AV 2 331 m 1978/83	8.5	10	1	4

cont.

SAMPLE Section/Horizon/Date	MASS (kg)	NUMBER OF CONODONTS	ELEMENTS per kg	NUMBER OF SPECIES
AV 4B 111.5 m 1983	3.0	1	<1	1
AV 4B 111.6 m 1983	1.0	15	15	4
AV 4B 120 m 1983	1.0	--	--	--
AV 4B 121 m 1983	1.0	--	--	--
AV 4B 128.5 m 1983	0.9	--	--	--
AV 4B 135.5 m 1983	0.9	--	--	--
AV 4B 136.5 m 1983	0.9	1	1	1
AV 4B 142.5 m 1983	1.0	--	--	--
AV 4 0 m 1979	4.4	291	66	13
AV 4 1 m 1979	8.3	343	41	15
AV 4 5 m 1979	3.7	174	47	14
AV 4 12 m 1979	8.8	113	13	9
AV 4 14.5 m 1979	2.2	1	<1	1
AV 4 136 m 1979	4.0	220	55	9
AV 4 150.5 m 1979	4.2	23	5	5
AV 4 165T m 1979	6.2	99	16	7
AV 4 203 m 1979	4.1	19	5	3
AV 4 211 m 1979	4.2	17	4	4
AV 4 231 m 1979	6.2	61	10	6
AV 4 240 m 1979	5.6	124	22	6
AV 4 248.5 m 1979	---	12	--	4
AV 5 69 m 1983	1.0	--	--	--
AV 5 178 m 1983	0.9	--	--	--
AV 5 190 m 1983	1.2	20	17	5
AV 5 200 m 1983	0.7	12	17	3
AV 5 209 m 1983	1.4	25	18	2
AV 5 215 m 1983	1.2	86	72	6
AV 6 250 m 1983	0.8	89	111	5
AV 6 258 m 1983	0.9	174	193	4
AV 7 27 m 1983	1.2	20	17	4
AV 7 268 m 1983	1.0	--	--	--
AV 7 430 m 1983	1.1	108	98	7
AV 7 524 m 1983	1.1	--	--	--

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